REPORT NO. FHWA/CA/TL-80/27

LONG-TERM PERFORMANCE OF THE FIRST REINFORCED EARTH WALL IN CALIFORNIA

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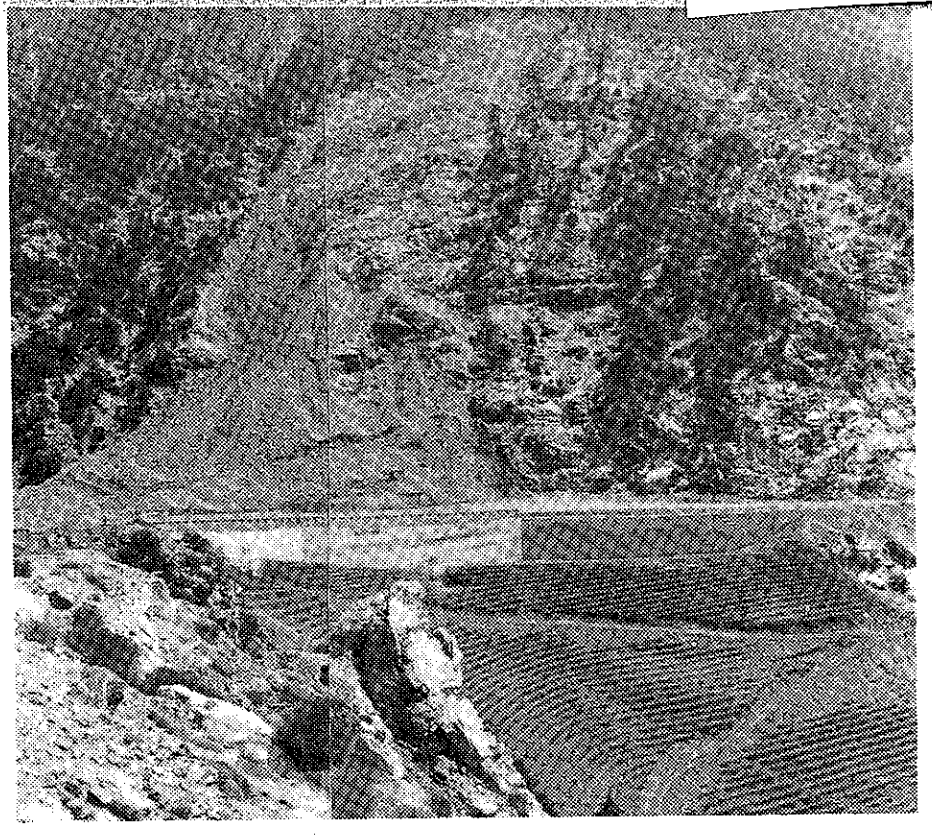

FINAL REPORT

AUG, 1980

NOTICE

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15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration for the research project "Continue Monitoring the Field Instrumentation in the Reinforced Earth Fill on Route 39."

16. ABSTRACT

This final report presents the long term performance of the first reinforced earth wall constructed by Caltrans in 1972. Field instrumentation since 1974 has indicated a continuing outward movement of the wall face at the south flank which has been documented in previous reports. Various remedial measures have since been instituted to improve wall stability. These are presented herein along with performance data. Final instrumentation measurements for this study were made in May 1980. They suggest continuing increases in strain of embedded reinforcing strips. Some significant reductions in strain rates have occurred since completion of additional buttressing and embankment reshaping. It is assumed that the embankment and foundation system is still readjusting to remedial measures. A condition survey in June 1980 revealed that the overall appearance of this facility is good.

Future performance will be monitored as required.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Reinforced earth, reinforcing strip, stress, strains, movement, long term performance, instrumentation, stability.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

August 1980

FHWA No. D-4-143
TL No. 632166

LONG TERM PERFORMANCE OF THE FIRST REINFORCED EARTH WALL IN CALIFORNIA

Study made by ..... Soil Mechanics and Pavement Branch

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Co-Investigator ..... Bobby L. Lister, P.E.

Research Conducted by ..... Jerry C. Chang, P.E.

Report by ..... Joseph B. Hannon, P.E.

APPROVED BY

Neal Andersen

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time			
(Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph)	.4470	metres per second (m/s)
	feet per second(fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs)	4.448	newtons(N)
	kips (1000 lbs)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds(ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

ACKNOWLEDGMENTS

The work reported herein is part of a research project authorized under work program HPR-1(13), D-4-143, in cooperation with the Federal Highway Administration, U.S. Department of Transportation.

The researchers wish to express their appreciation to District 07 Surveys personnel for their assistance in establishing and monitoring reference points as part of this performance study. Special thanks is also extended to the various Maintenance, Materials, Design and Hydraulics personnel of District 07 for their assistance and cooperation in making visual observations, reporting field conditions, planning and/or making remedial corrections and improvements to maintain the long term stability of the reinforced earth wall.

Personnel of the Soil Mechanics and Pavement Branch of the Transportation Laboratory who assisted with this research project include the following:

Frank Champion, Bobby Lister and Ronald Thompson who monitored the long-term field instrumentation and David Castanon who not only worked with instrumentation data collection but also plotted the data and coordinated the field work with District 07 Surveys personnel.

Special appreciation is also extended to Albert Sequeira and to the various other personnel of the Electrical and Electronics Instrumentation Section of the Transportation Laboratory who provided consultation and assistance relative to strain gage technology and evaluation. The efforts of all those associated with the original instrumentation of this project should also be recognized.

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INTRODUCTION

Reinforced earth was introducted in the United States with the construction of the first facility by the California Department of Transportation in 1972 (Photos 1 and 2). This installation, located on Route 39 in Los Angeles County, has been the subject of comprehesive field instrumentation monitoring over the last seven and one-half years to evaluate its performance. This work was federally financed under Research Project TL 632115, D-4-93, titled "Earthwork Reinforcement Techniques". Initial performance through June 1973 was reported by Chang in 1974 (1) and by Chang and Forsyth (2). Other later reports also discuss its initial behavior (3,4,5,6).

Monitoring of field instrumentation was continued through June 1977 under a separate Type "B" study initiated in 1975. Data collected from these instrumentation readings and monitorings of visual performance indicated that the south flank of the reinforced earth wall was continuing to move outward. Increasing strain on some of the steel strips indicated that stress levels were beginning to exceed the steel's proportional limit of 35,000 pounds per square inch.

Various assumptions have been made as to the reasons for the excessive reinforcing steel strain and the reduced stability of the system. These were contained in an interim report by Chang in 1978 (7) and are also reported herein. In order to evaluate the long term performance of this facility, it was necessary to change the Type "B" study to a Type "A" study to allow for additional monitoring. A revised work plan to accomplish this objective was approved by FHWA in December 1977.

This final report presents the results of field monitoring and describes remedial measures to improve stability through the spring of 1980.

CONCLUSIONS

1. Reinforced earth has proven to be an effective landslide correction at this location.

2. Based on field reviews of similar slide locations on Route 39, it is believed that normal embankment construction would have failed or been subject to severe damage if constructed.

3. Both the temporary and the permanent slope buttressing corrections proved successful in maintaining stability of the wall.

4. Individual reinforcing strips are continuing to show increased strain. However, some elements have stabilized while others may be readjusting to the additional buttressing of the wall.

5. Additional performance monitoring should verify stability of the wall.

6. The surface drainage behind the wall is not completely effective in diverting runoff to the culvert inlet. Further modification may be necessary in the future.

RECOMMENDATIONS

It is recommended that both visual and instrumentation monitoring be continued as an informal state financed study to assess the future performance of the reinforced earth wall. Reestablishment of monuments on the new buttress and on top of the wall are essential for monitoring future performance.

IMPLEMENTATION

Reinforced earth is presently being considered for use by Caltrans as an alternative to other retaining wall systems. Several reinforced earth walls have been constructed in California by Caltrans and other jurisdictions. Studies have been conducted by Caltrans of approximately 30 sites to determine the feasibility of earthwork reinforcement. Several sites are under consideration at the present time.

Numerous methods for reinforcing soil have been developed over the years, some as early as biblical times. Concurrent with the early phase of the study reported herein, Caltrans developed an improved system which is an alternative to reinforced earth construction. The Caltrans System (Mechanically Stabilized Embankment) is licensed through a joint agreement under the Reinforced Earth Company Patent for use on Caltrans projects. The Caltrans System is also specified as an alternative to normal retaining wall construction.

CHRONOLOGY

The reinforced earth wall on Route 39 was built over an active landslide area that would have posed serious problems for conventional embankment construction. The plan and profile of the constructed facility are shown in Figure 1. Since the wall's completion in 1972, several winter storms have continued to deposit slide debris above the roadway.

Field data obtained from 1973 through 1976 indicated continuous increases in steel stresses in some cases exceeding the proportional limit of 35,000 pounds per square inch for the steel strips. (Refer to Figures 2 through 7.) The location of the various strain gages and other instruments are shown on Figure 8. Horizontal movements have continued at the top and bottom of the wall along the south flank. These movements have been recorded on the monuments shown on Figure 9 and are presented on Figures 10 and 11. The increases in steel stresses and horizontal movements may have been caused by additional earth pressure from the continuous deposit of debris from the slide behind the wall (Photo 3). Several other conditions not anticipated in the original design have also developed since construction. A mud slide in September 1976 deposited several feet of debris on the roadway subsequent to an intense 6 to 10 inch rain storm during a 24 hour period. A maximum settlement in excess of 4 feet has also been experienced since the beginning of construction which may have sheared drainage collector pipes on the back slope behind the wall. Seepage pressures may have also developed due

to surface water moving directly into the highly permeable embankment from natural drainage swales in back of the wall, when these flows were unable to reach the culvert inlet (Photo 4) or due to a plugged inlet structure (Photo 5).

Seepage through the embankment below the wall and storm water runoff over the wall and down the slope face also contributed to severe erosion of the toe buttress and the embankment slope below the wall's south flank. The mud flow which occurred in September 1976, went completely over the roadway and deposited large amounts of slide debris above the wall and spilled some over the top. The resultant embankment slope up to the base of the wall along the south flank was approximately 1.5:1 following the winter storm of 1976, as opposed to the constructed slope of 1.75:1 which was still intact for the remainder of the wall. This erosion and sloughing reduced the available lateral support considerably.

As a result of the above conditions the Transportation Laboratory requested new cross-sections and performed a re-evaluation of the overall stability of the embankment and foundation system in the summer of 1977. A conservative factor of safety for the eroded slope condition was 0.89. By raising the height of the toe buttress at the base of the wall an additional 5 ft and flattening the slope to 1.75:1, the factor of safety could be increased to 0.98. A 10 ft increase in toe buttress height with the 1.75:1 embankment slope would only slightly increase the factor of safety to 1.01 or to an overall increase of 13%.

Several field inspection trips to the project resulted in recommended procedures to improve the stability of the slope. It was generally agreed that correction should include the following elements:

1. Improve surface drainage at the inlet to the existing 84 inch CSP and seal the ponding area to preclude percolation through the reinforced embankment. The seal could be placed and protected with about two feet of fine-grained relatively impermeable soil. Provisions would also be made to directly intercept two drainage channels which were discharging directly into the ponding area.

2. Mud flow debris between the roadway and the wall, and also to the east of the wall were to be removed to lessen the load on the wall (Photo 6). The debris material could be used to flatten the existing eroded slope below the south flank of the wall and raise the height of the buttress at the wall base which would provide increased lateral resistance to movement.

The large amount of slide debris which was being generated on this particular highway was also posing problems for maintenance forces. To cope with this situation it was proposed to provide a storage area, down slope from the reinforced earth wall. As part of the above slope flatting project, a reinforced buttress fill could be placed at the toe of slope that would allow for deposit of additional slide debris. Because of the cost of these corrective measures, the project could not be advertised until the following year (1978). The achievement of additional stability for protection of the wall and roadway however was considered to be of the utmost importance. Consequently temporary remedial work was recommended

prior to the winter storms. It was proposed that maintenance forces using rented equipment and Day Labor place a temporary buttress in front of the wall by pushing slide debris over the top and allowing the debris to form its own slope. This procedure was necessitated by lack of access to the base of the wall. Consequently, material had to be placed uncompacted.

The primary area of concern was along the south flank where strain gage instrumentation and reference points indicated continuing outward movement. Approximately 50,000 cu. yds. of material were pushed over the wall face and down the slope during November and December 1977 (Photo 7). This remedial measure provided temporary buttressing through the winter of 1977 at a fraction of the cost for the proposed engineered (compacted) slope correction. However, during the winter of 1977-1978, erosion occurred on the temporary buttress which steepened the slope and based upon a stability analysis reduced the factor of safety (Photos 8 and 9).

The strain gage data observed on June 28, 1978, indicated that the stresses in the steel strips embedded in the center chord and the south flank were continuing to increase (Figures 2 through 7). However, the increases in steel stresses in the south flank were more significant than those in the center chord of the wall. These continual increases in steel stresses along with newly discovered cracks on the pavement of the north flank indicated that the south flank was still moving outward.

During this period, a series of cracks appeared in the pavement on top of the north flank of the wall near roadway

centerline for a distance of about 40 feet (Photo 10). It was apparent that reshaping of the slope below the wall would be mandatory prior to the next winter season. Recommended remedial measures by the Transportation Laboratory to improve wall stability were submitted to District 07 in October 1978. These measures included flatting the embankment slope, interception and diversion of surface runoff and removal of additional slide debris behind the wall plus repair of the drain system below the wall.

The District was unable to institute the remedial work prior to the 1978 winter season due to weather and snow conditions. Consequently, the project was delayed until July 1979.

Since the strain measurements on the reinforcing strips continued to suggest stresses beyond or near their proportional limit, the long term reliability of the strain gages was questioned. It was thus decided to retrieve several buried strain gages to verify that they were still functioning properly. The most accessable gages were those on the back of the skin plate. These gages were located at Station 551+75, Level B (See Photo 11 and refer to Figure 8.) The retrival was accomplished as shown in Photos 12 through 16 by removal of a small section of face plate. Tensile tests up to 6,000 lbs performed on samples of the retrieved skin plate with the gages attached indicated that these strain gages were functioning properly. This, in turn, indicated the probable validity of data developed from the buried strain gages on the reinforcing strips.

During the cleanup operation following the winter storm season of 1978-79, a cavity was discovered by maintenance

personnel below the pavement surface near the south flank of the wall above the pervious sand blanket behind the reinforced earth wall. (See Figure 1 Profile.) Maintenance forces were requested to identify the extent of the cavity and backfill it with either pea gravel or jetted sand. This would be followed by sealing the roadway surface with asphalt concrete to prevent infiltration of surface water. Maintenance elected to jetty sand into the cavity, which on observation appeared to provide a satisfactory repair. A similar crack was repaired in the same area during the spring of 1973.

It was necessary to extend the research project through Fiscal Year 1979-80 because of these new developments and the delays in completion of the remedial work both for the buttress resloping and the sealing of the drainage channel above and behind the wall. This would allow adequate time to monitor these operations visually and by instrumentation.

The earthwork resloping operation below the wall was completed on August 7, 1979 by the Foothill Maintenance Station using Day Labor. This work involved: removing the temporary buttress and raising the berm in front of the wall toe by 10 feet as recommended (Photo 17); resloping the embankment (Photo 18); restoring the 84-inch drain pipe (Photo 19); constructing the access road from the top of the embankment to the toe of the slope (Photo 20); and building a catchment berm at the toe of the slope (Photo 21). The completed slope was terraced to minimize future erosion.

Additional readings of the strain gages on the steel strips were made on August 29, 1979, three weeks after completion

of the above work. These measurements indicated that while the strains on some of the reinforcing strips had stabilized, others had increased since the last measurements in October 1978. (Refer to Figures 2 through 7.)

A contract to seal the drainage channel behind the wall and prevent infiltration of surface water that would lead to additional seepage pressure on the wall was completed in December 1979.

The last series of instrumentation measurements and visual observations were delayed until May 1980 by snow and numerous rock and earth slides on roads leading to the project.

Most of the surface monuments on top of the wall were located and surveyed by District 07 Survey personnel. Destroyed monuments on top of the wall and on the new toe buttress at the base of the wall require reestablishment to monitor long term performance. The approximate location of these monuments are shown in Figure 9.

ANALYSIS OF DATA

Slope indicator locations SI-1 through SI-3 (Figure 1) were buried by slide debris during the winter of 1976-1977. Attempts to relocate these installations were unsuccessful. Since measurements prior to 1977 did not indicate a deep seated movement, the installation of replacements was considered to be unnecessary. It was, therefore, decided to utilize the Series "A" and "C" surface monuments and strain gage readings to detect additional movement.

Strain gage measurements obtained on the reinforcing strips have shown continuous increases since the last reported readings in June 1977. However, some significant decreases in strain rates have occurred since placement of the temporary buttress in December 1977 and also after completion of the correctional work during the fall and winter of 1979. (Refer to Figures 2 through 7 and Tables 1 through 4.)

Since some movement is still occurring, it is assumed that the embankment and foundation system is still readjusting to the added buttress loading and the resloping of the embankment below the wall. Additional monitoring of instrumentation is required to better evaluate future performance and overall stability of the wall.

No recent measurements to detect horizontal movement were obtained on the Series "A" monuments at the base of the wall, as they were buried on the south flank by the temporary buttress placed prior to the 1978 measurements. The monuments on the north flank were also buried by the August 1979 slope correction and buttressing. The maximum total

recorded horizontal movement was 7.80 inches at Sta. 13+00 on July 1, 1977. (Refer to Figure 10 and Table 5 for measurements through 1978.)

Measurements made on Series "C" monuments on top of the wall suggest 1.5 to 1.9 inches of additional horizontal movement since 1978 for the north flank and center chord sections of the wall. (Refer to Figure 11 and Table 6.) These measurements represent horizontal movement since 1978, the majority of which probably occurred prior to the correctional work in 1979. The measurements, therefore, do not provide a good assessment of the effectiveness in correcting the overall stability of the wall.

The maximum total recorded horizontal movement was 12.48 inches on May 5, 1980, and also occurred at Sta. 13+00.

The relative magnitude and direction of movement of the wall has been manifested in the steel face elements as shown by photographs taken June 28, 1980. Photos 22, 23 and 24 show the extension and separation at the joints between skin plates on the north flank due to axial tensile stresses in the face. (Refer to skin element numbers 46, 57 and 69 in Tables 7 and 8.) This condition also occurs but to a lesser extent at the end of the south flank.

Photos 25 and 26 show the effects of the tremendous axial compressional forces that have been experienced by the center chord of the wall due to a buildup of lateral forces as the wall has moved outward. Note the distortion and gouging of end plates that has occurred. (Refer to skin element numbers 8, 25 and 43 in Tables 7 and 8.)

Settlement of the wall has continued since construction. A total settlement of 3.5 ft was recorded on settlement platforms SP1 through SP4 at Sta. 551+75, Level A, through December 1973. (Refer to Figure 8.) The readout at this level was destroyed after that date. Measurements on Series "A" and "C" monuments have provided a continuation of the settlement record. Based on these measurements, about 1.0 ft of additional settlement has occurred through May 1980. Measurements on Series "A" monuments show a maximum of 0.5 ft of settlement between 1973 and 1978 (Figure 12). No settlement measurements are available for Series "A" monuments after 1978 since they were buried by the correctional work. Series "C" monuments at the top of the wall suggest a maximum of 1.0 ft of settlement between 1973 and May 1980 (Figure 13). About 20% of that occurred since 1978.

To provide continuous monitoring of any future movements, new Series "A" monuments were established at the base of the wall to detect both horizontal and vertical movements. All destroyed Series "C" monuments on top of the wall will also be reestablished for future monitoring.

REVIEW OF FACILITY'S PERFORMANCE

A final condition survey was obtained on June 12, 1980. It was noted that an estimated stream flow of about 5 gal./min. of water was coming down the slope behind the wall and entering the upper portion of the drainage channel (Photo 27). This flow disappeared into the channel about 3 ft. beyond a concrete lined approach apron. It was apparent therefore that the drainage correction was not completely satisfactory since none of this flow was reaching the culvert inlet. However, the drainage facility was in excellent condition considering the 35 inches of rainfall that occurred this past winter season since the channel was repaired.

A crack count made during the final condition survey indicated several 1/4 to 3/8 inch wide cracks in the pavement behind the north flank of the wall. These are shown in Figure 14 and are the same cracks observed in 1978 (Photo 10). Hairline cracks were also observed in the patched pavement area behind the wall's south flank (Photo 28). These cracks were reflecting up from the interface between the patch and the old pavement. The pavement and roadway above the wall are otherwise in excellent condition.

The fill slope below the wall is in generally good condition with some surface erosion (Photos 29 through 31), most of which has occurred at the south end of the wall below a rock outcrop. Erosion is concentrated in this area due to surface water runoff over the rock face.

No evidence of water seeps or surface flow was observed on the slope, at or below the toe of the slope and in the

vicinity of the pipe outlets, as viewed through field glasses from the top of wall.

Future monitoring of instrumentation is necessary to evaluate the long-term performance of this facility.

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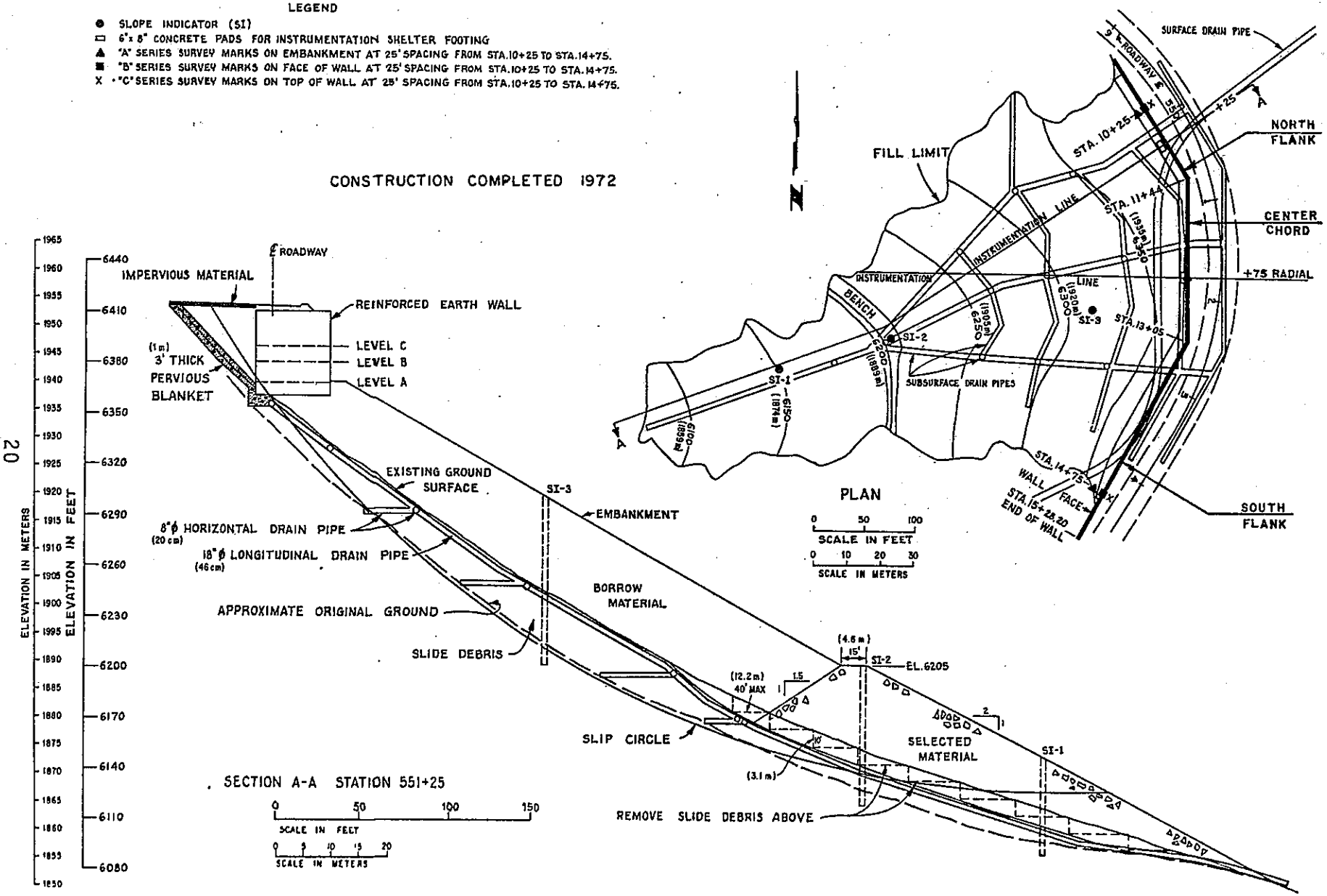
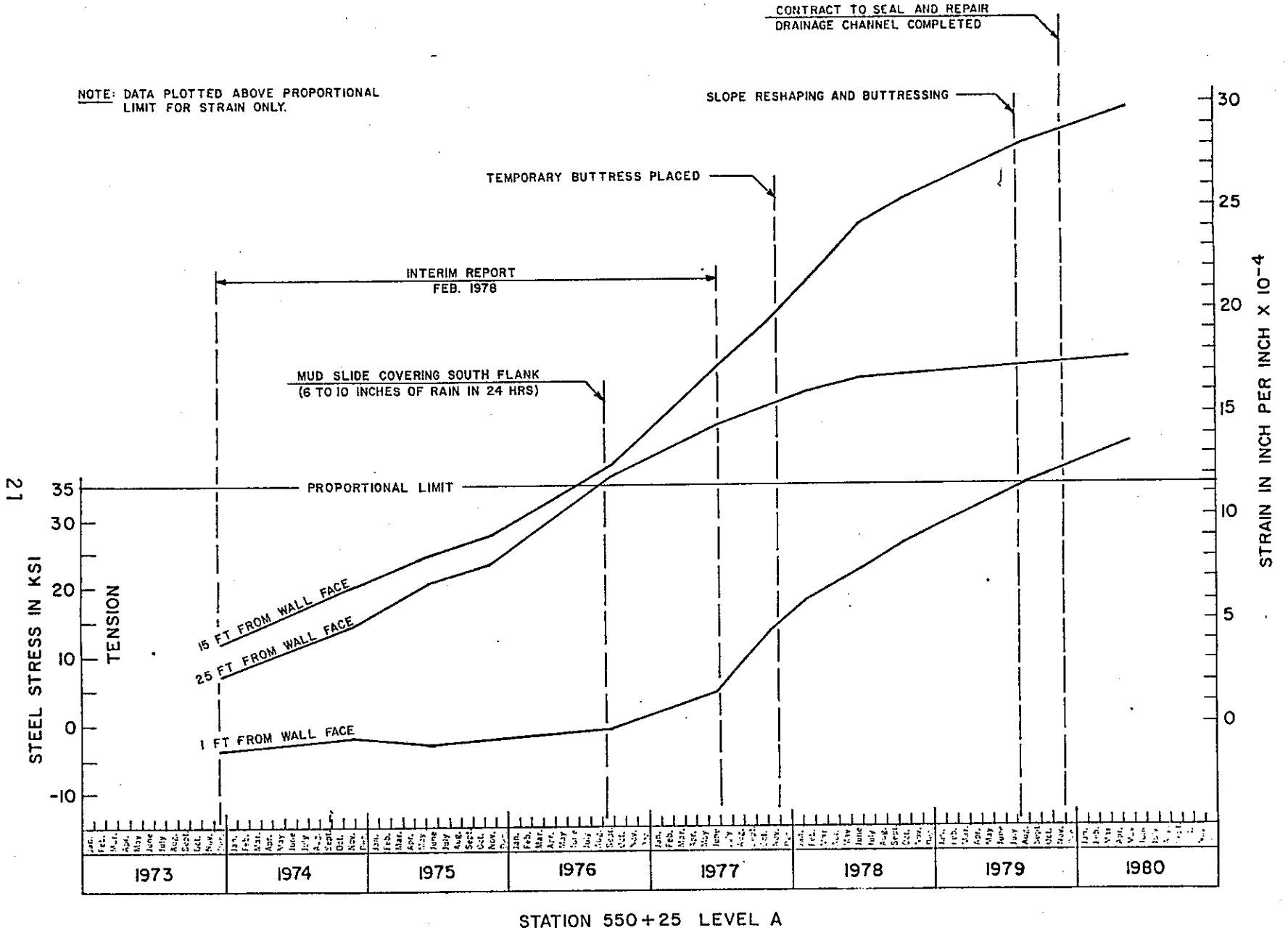


PLAN AND PROFILE

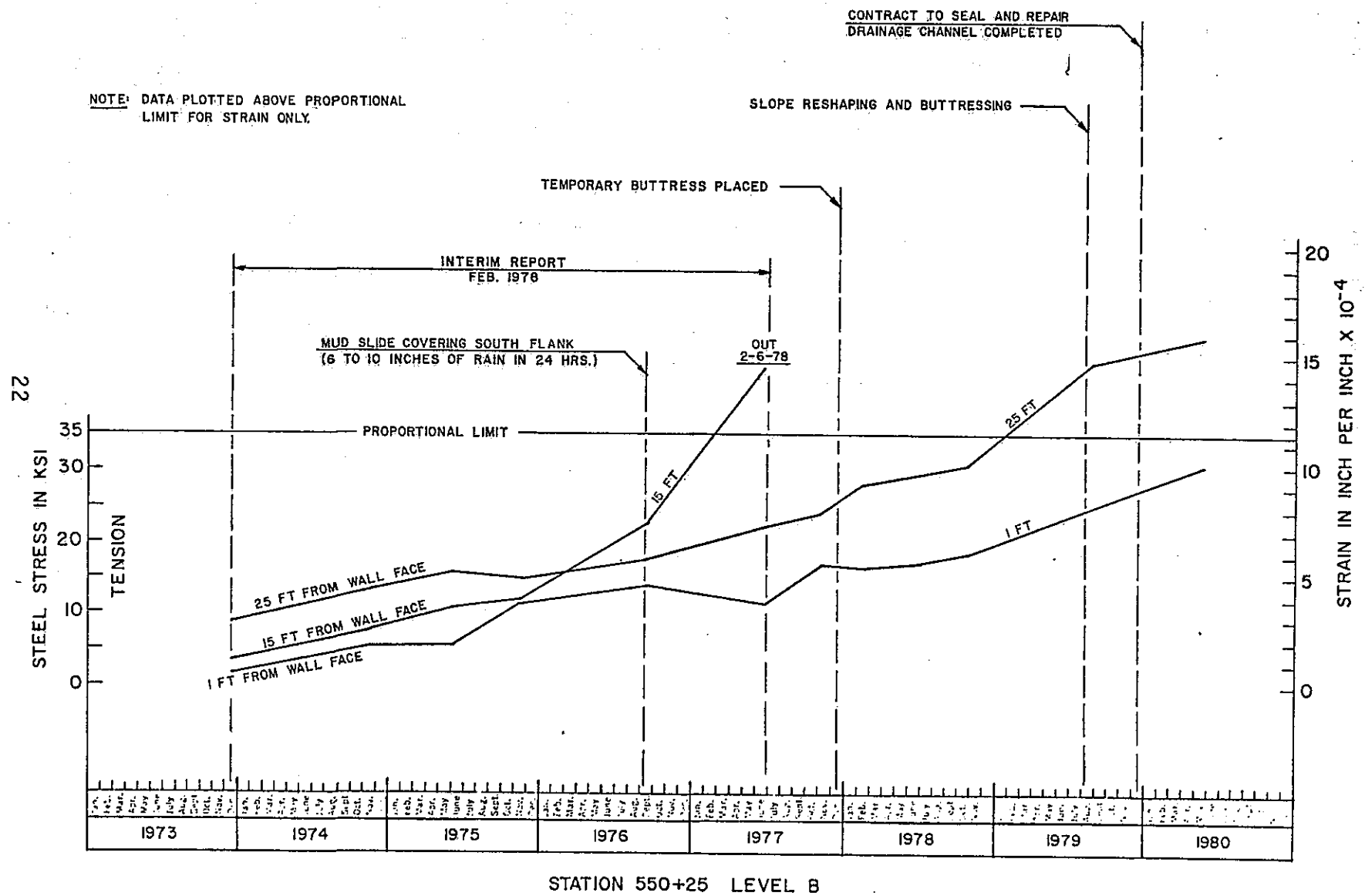
FIGURE 1



STATION 550+25 LEVEL A

HISTORY OF STRESSES & STRAINS IN STEEL STRIPS

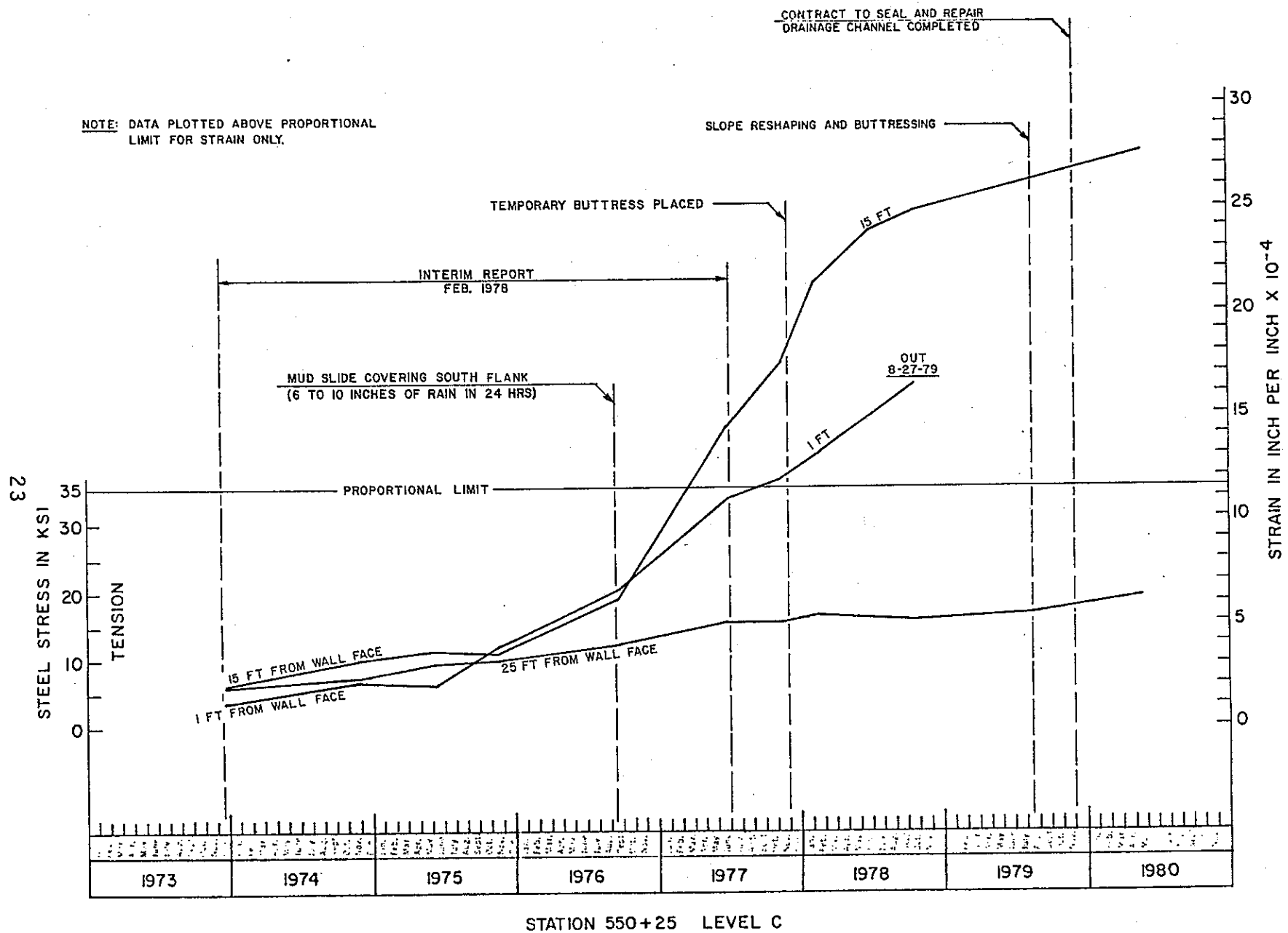
FIGURE 2



STATION 550+25 LEVEL B

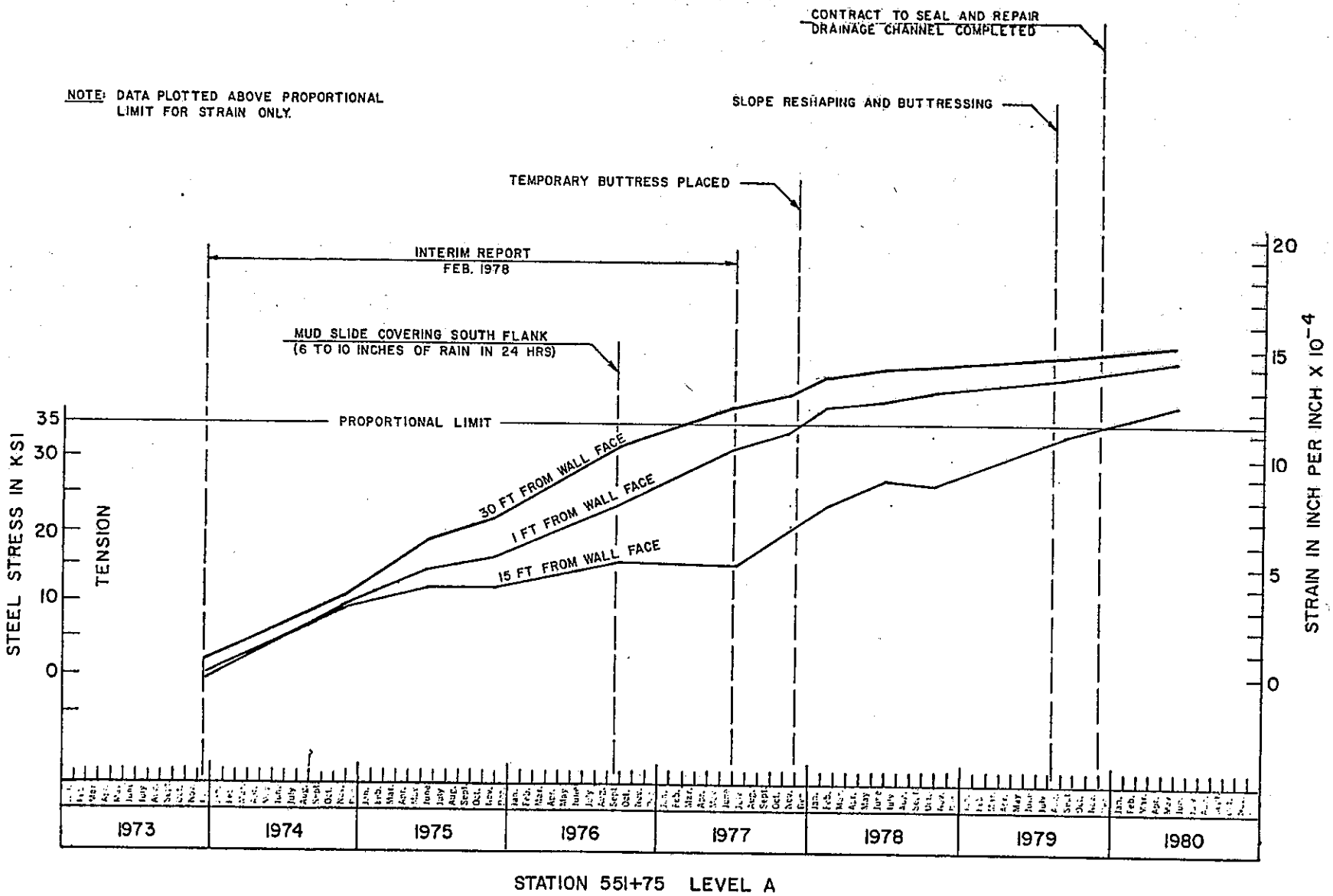
HISTORY OF STRESSES & STRAINS IN STEEL STRIPS

FIGURE 3



HISTORY OF STRESSES & STRAINS IN STEEL STRIPS

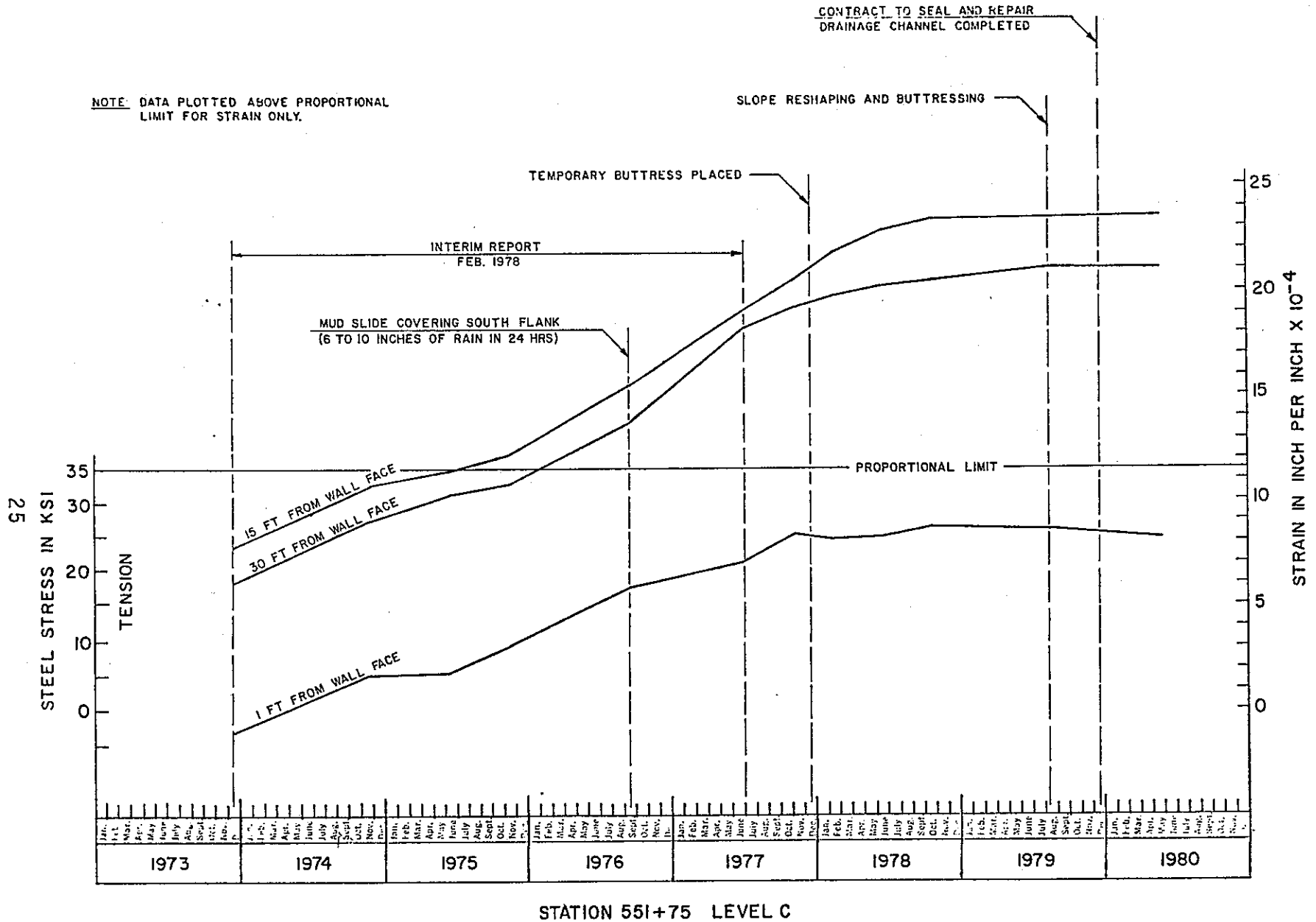
FIGURE 4



STATION 551+75 LEVEL A

HISTORY OF STRESSES & STRAINS IN STEEL STRIPS

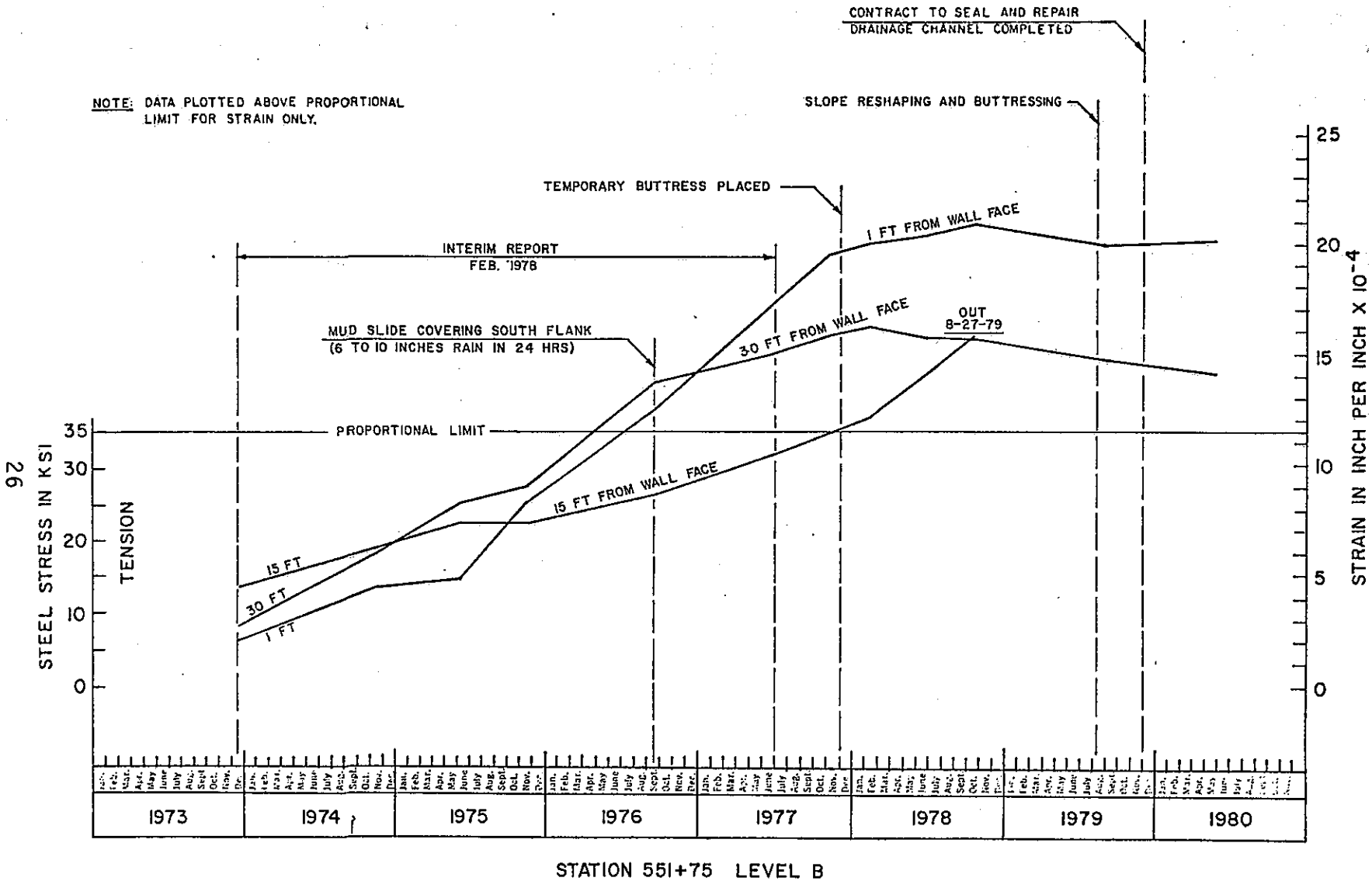
FIGURE 5



STATION 551+75 LEVEL C

HISTORY OF STRESSES & STRAINS IN STEEL STRIPS

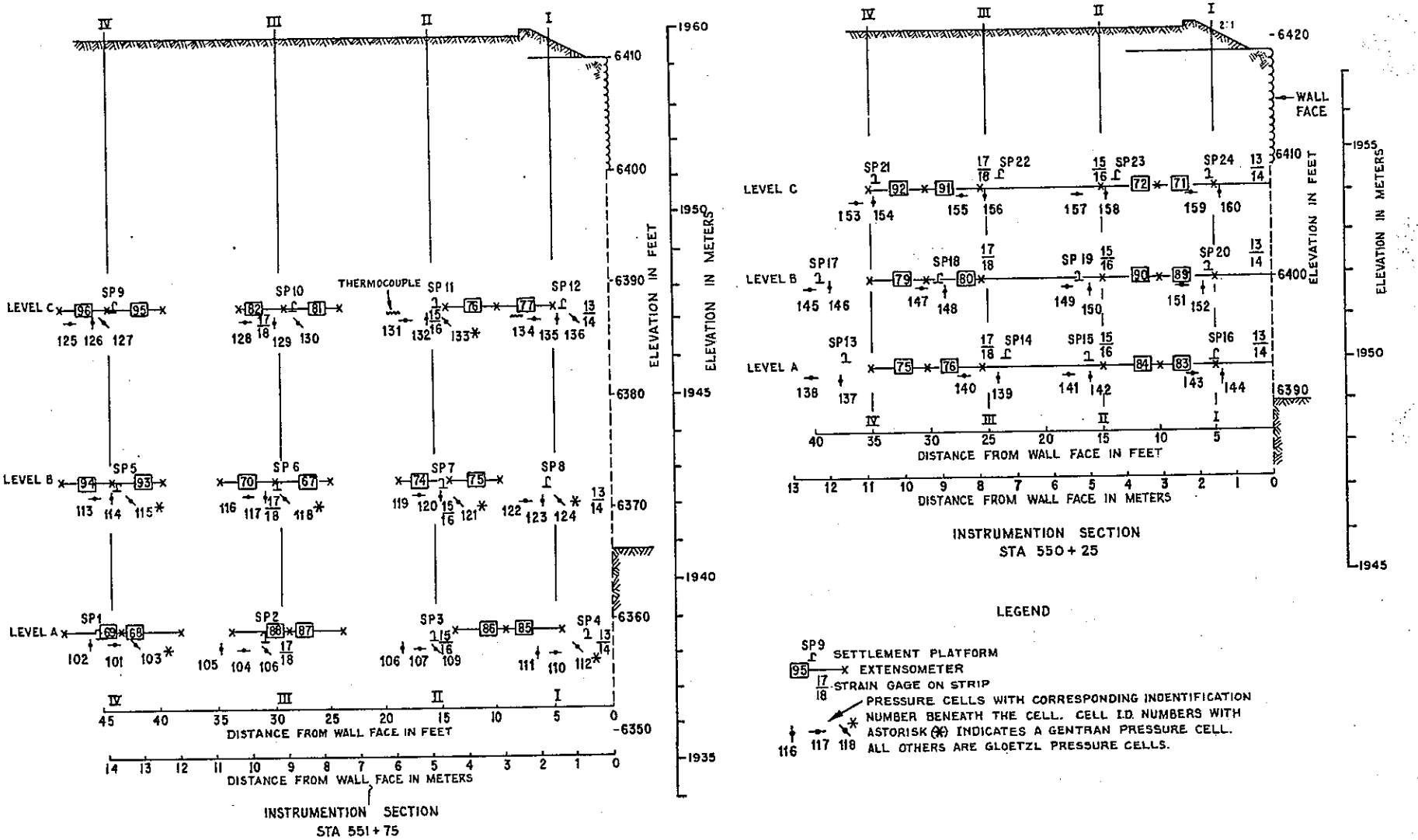
FIGURE 6



STATION 551+75 LEVEL B

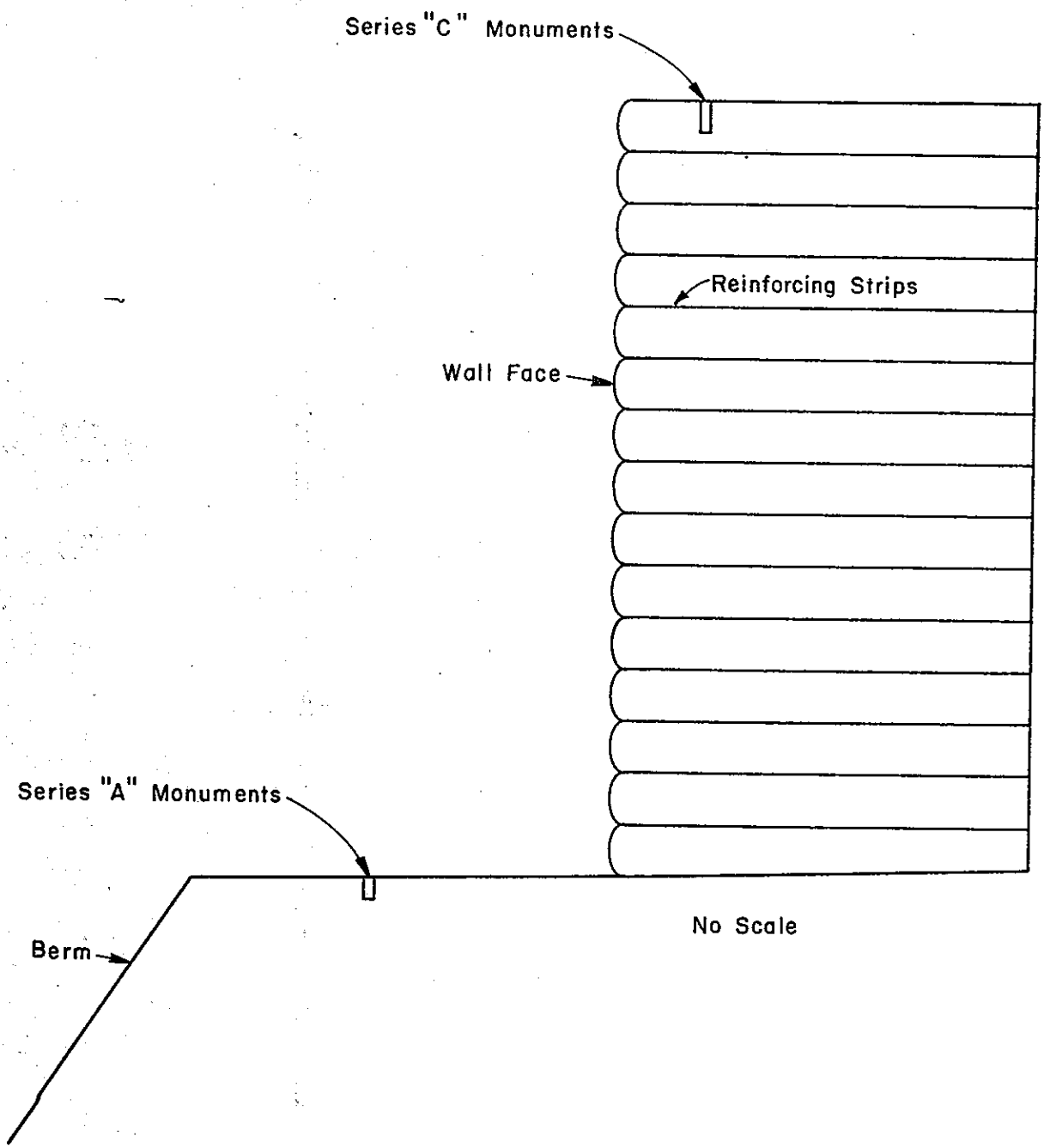
HISTORY OF STRESSES & STRAINS IN STEEL STRIPS

FIGURE 7



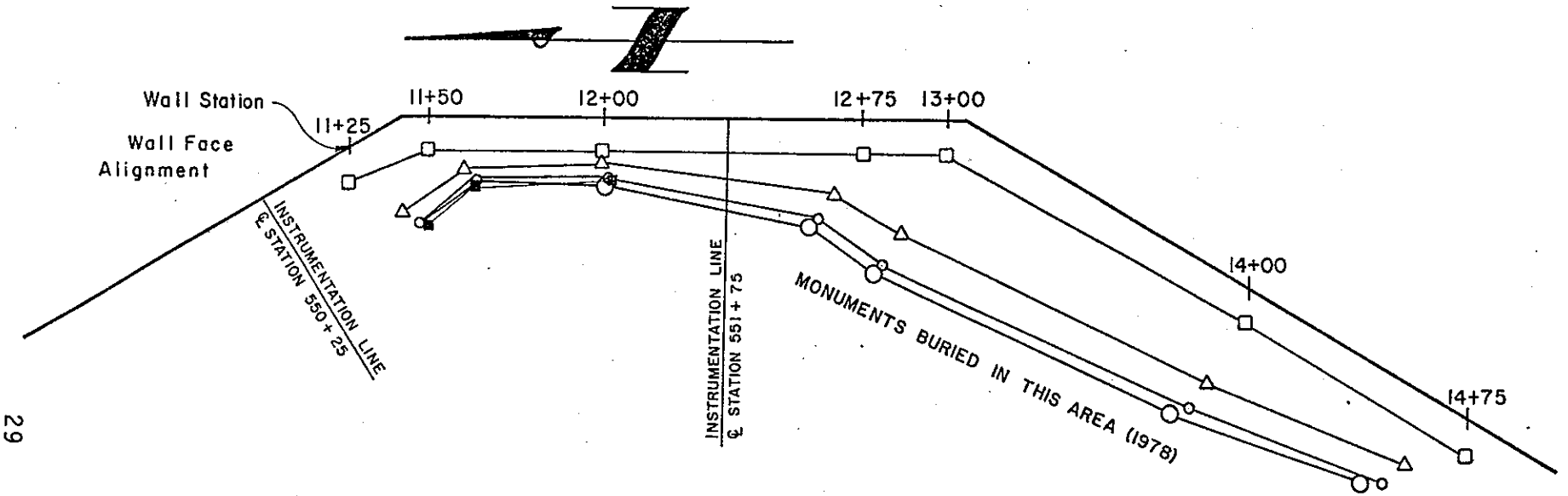
INSTRUMENTATION SECTIONS

FIGURE 8



CROSS SECTION OF REINFORCED EARTH WALL

FIGURE 9



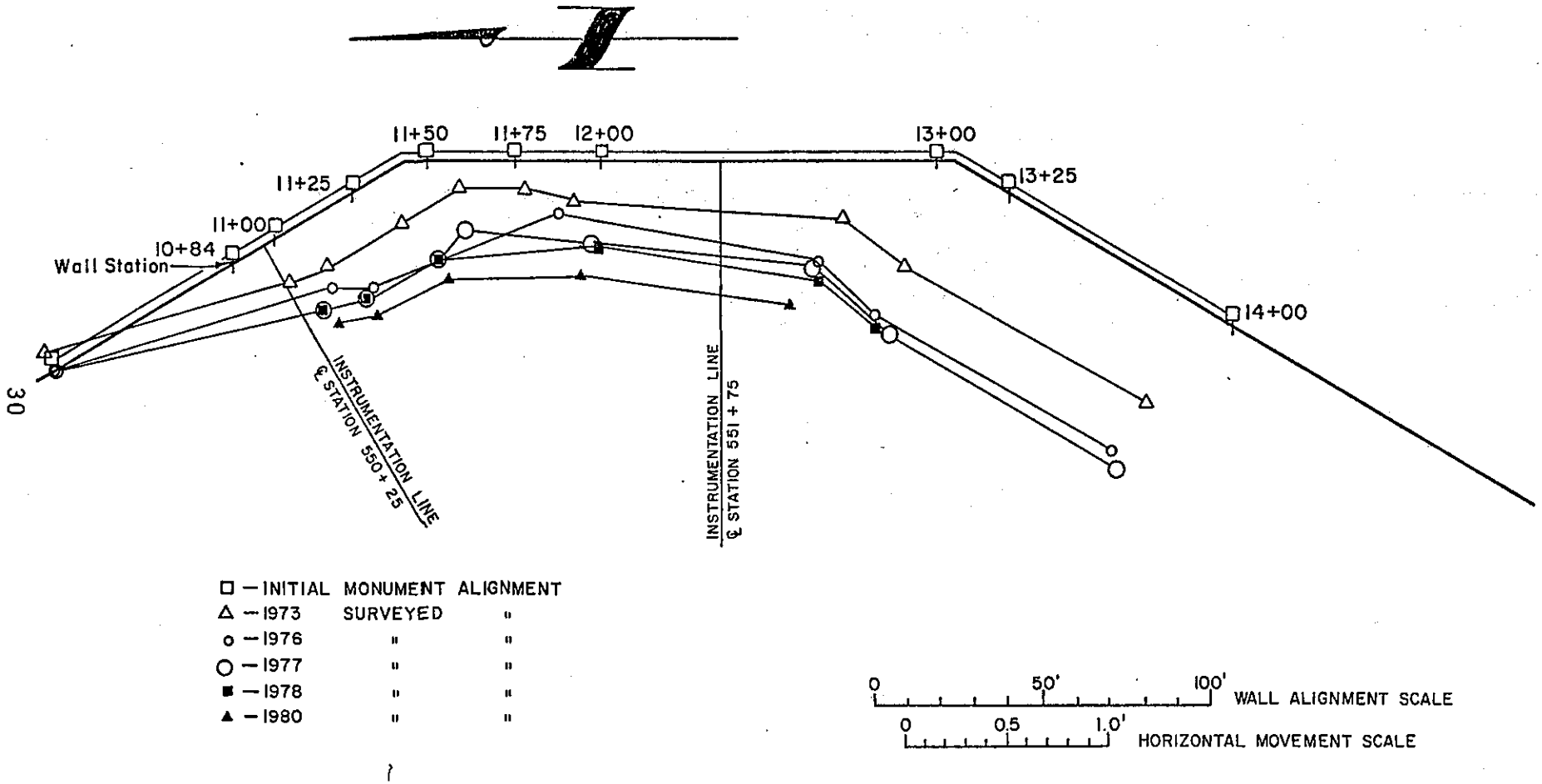
NOTE: ALL MONUMENTS BURIED BY AUGUST 1979 SLOPE CORRECTION AND BUTTRESSING.

□ – INITIAL MONUMENT ALIGNMENT
△ – 1973 SURVEYED "
○ – 1976 " "
◯ – 1977 " "
■ – 1978 " "

0 50' 100' WALL ALIGNMENT SCALE
0 0.5 1.0' HORIZONTAL MOVEMENT SCALE

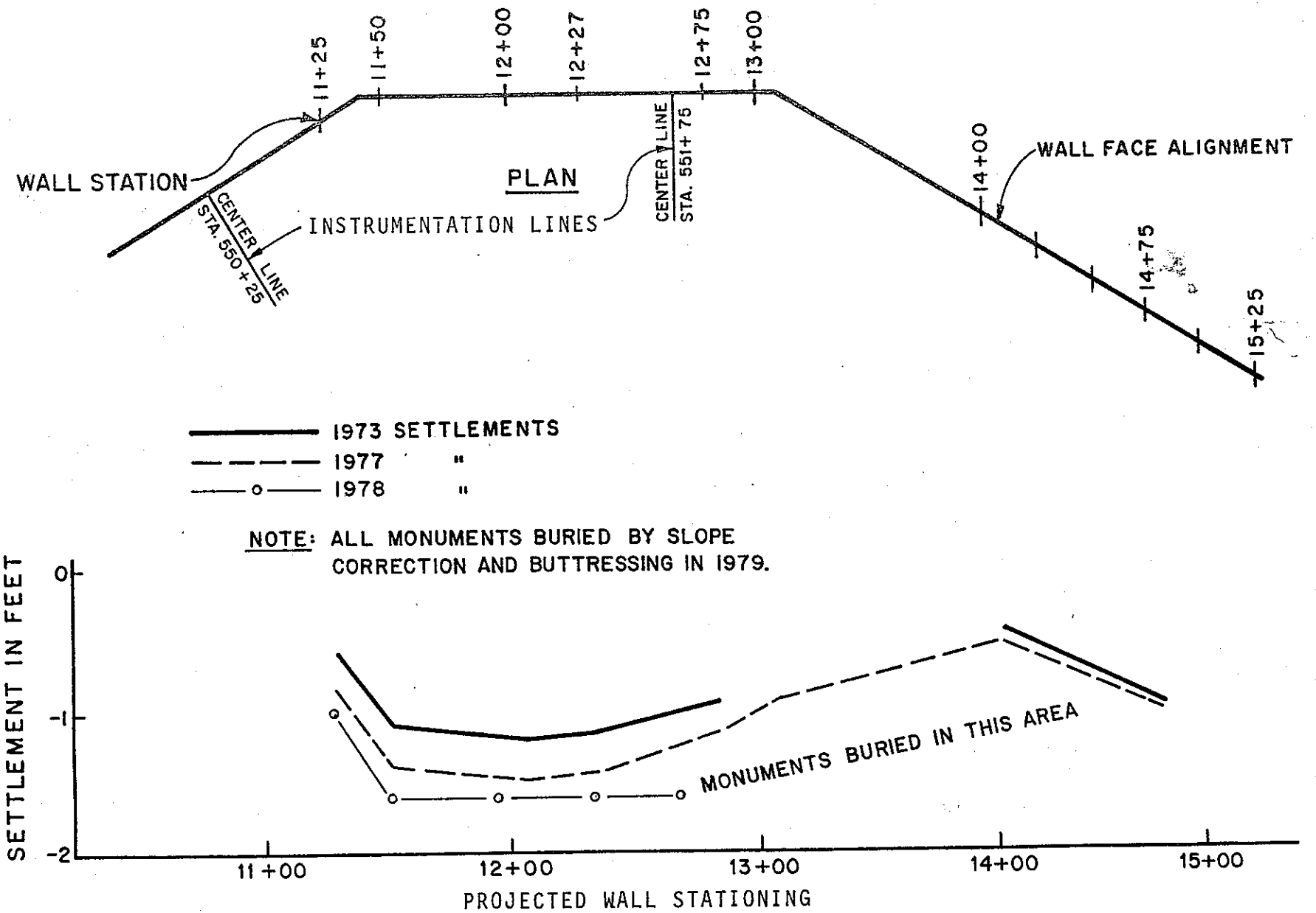
HORIZONTAL MOVEMENTS AT SERIES "A" MONUMENTS

FIGURE 10



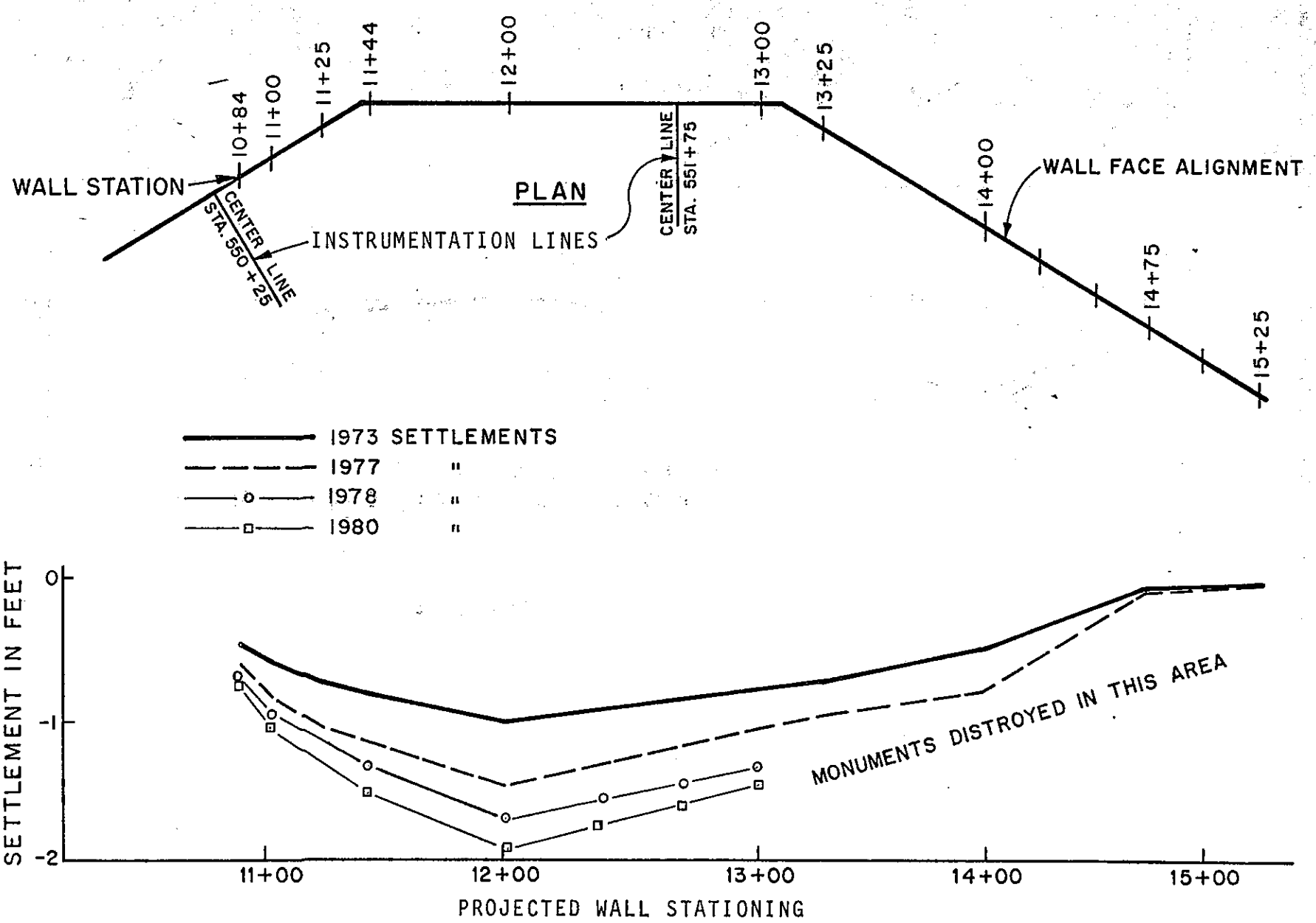
HORIZONTAL MOVEMENTS AT SERIES "C" MONUMENTS

FIGURE 11



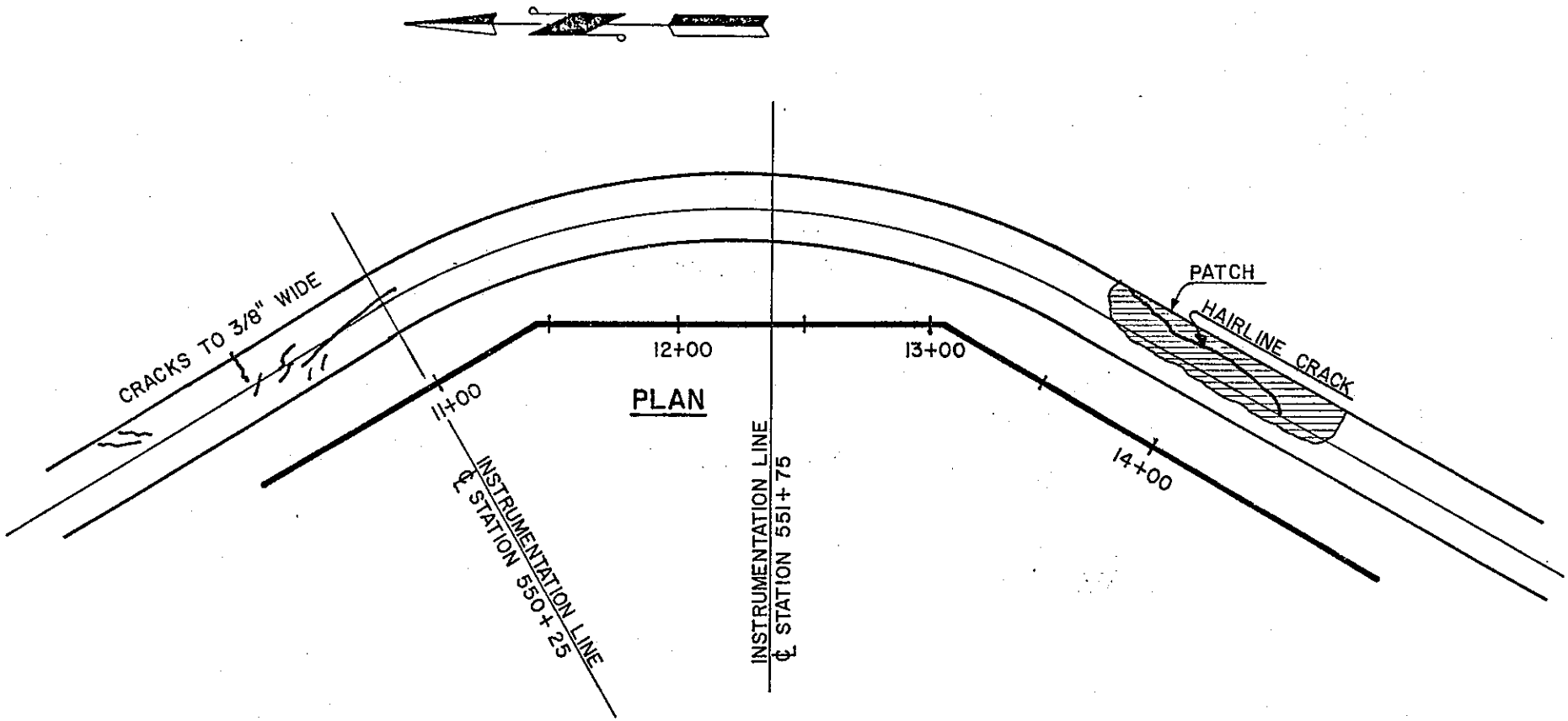
SETTLEMENTS AT SERIES "A" MONUMENTS

FIGURE 12



SETTLEMENTS AT SERIES "C" MONUMENTS

FIGURE 13



PAVEMENT CONDITION STUDY, JUNE 1980

FIGURE 14

TABLE 1: STRAIN IN STEEL STRIPS IN INCH PER INCH X10^{-6}

STATION	DATE	LEVEL C			LEVEL B			LEVEL A		
		GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET		
		1	15	25	1	15	25	1	15	25
550+25	12-17-73	130	187	185	45	117	285	-121	396	232
	11-20-74	213	311	222	174	255	425	-60	650	475
	6-5-75	190	356	290	178	349	500	-98	805	666
	11-18-75	376	336	312	366	367	469	-63	892	774
	9-22-76	653	593	382	452	737	568	-20	1252	1204
	6-2-77	1096	1428	488	365	1439	712	154	1720	1442
	11-2-77	1177	1753	492	543	N.F.*	780	433	1945	1526
	2-6-78	1306	2128	531	529	-	907	584	2153	1612
	6-28-78	1479	2372	515	545	-	-	724	2405	1680
	10-17-78	1648	2472	505	603	-	993	874	2533	1679
	8-27-79	N.F.*	2624	522	792	-	1471	1148	2803	1733
	5-15-80	-	2750	615	1000	-	1583	1348	2934	1772

*Nonfunctioning

TABLE 2: STRAIN IN STEEL STRIPS IN INCH PER INCH X10^{-6}

STATION	DATE	LEVEL C			LEVEL B			LEVEL A		
		GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET		
		1	15	30	1	15	30	1	15	30
551+75	12-17-73	-27	761	590	204	438	284	-7	2	70
	11-20-74	157	1067	895	432	626	588	302	298	353
	6-5-75	169	1133	1058	475	719	820	451	389	592
	11-18-75	298	1207	1077	821	720	907	517	386	703
	9-22-76	574	1539	1370	1255	856	1382	767	501	1041
	6-2-77	681	1895	1796	1737	1074	1498	106	501	1217
	11-2-77	812	2050	1913	1951	1146	1584	1119	669	1278
	2-6-78	795	2173	1976	1997	1221	1617	1223	763	1349
	6-28-78	815	2285	2022	2034	1421	1580	1255	905	1385
	10-17-78	842	2327	2037	2096	1586	1563	1303	886	1410
	8-27-79	836	2343	2102	2001	N.F.*	1480	1359	1094	1450
	5-15-80	789	2348	2077	2010	-	1408	1431	1243	1500

*Nonfunctioning

TABLE 3: STRESSES IN STEEL STRIPS IN KSI

STATION	DATE	LEVEL C			LEVEL B			LEVEL A		
		GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET		
		1	15	25	1	15	25	1	15	25
550+25	12-17-73	3.5	5.6	5.5	1.1	3.4	8.6	-3.5	11.9	6.7
	11-20-74	6.3	9.2	6.5	5.0	7.5	12.5	-1.7	19.4	14.3
	6-5-75	5.6	10.7	8.6	5.4	10.4	14.9	-2.8	24.0	20.0
	11-18-75	11.3	10.2	9.3	10.9	10.9	14.5	-1.7	26.7	23.0
	9-22-76	19.3	17.6	11.3	13.4	21.7	16.9	-0.5	-	-
	6-27-77	32.7	-	14.6	11.0	-	21.2	-4.4	-	-
	11-2-77	-	-	14.6	16.1	N.F.*	23.4	12.7	-	-
	2-6-78	-	-	16.2	16.1	-	27.7	17.8	-	-
	6-28-78	-	-	15.7	16.6	-	-	22.1	-	-
	10-17-78	-	-	15.4	15.4	-	30.3	26.6	-	-
	8-27-79	N.F.*	-	15.9	24.1	-	-	35.0	-	-
	5-15-80	-	-	18.8	30.5	-	-	-	-	-

Note: All stresses in excess of 35.0 KSI are above the proportional limit of the steel and their computed values are approximate only.

*Nonfunctioning

TABLE 4: STRESSES IN STEEL STRIPS IN KSI

STATION	DATE	LEVEL C			LEVEL B			LEVEL A		
		GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET			GAGE DISTANCE FROM WALL FACE IN FEET		
		1	15	30	1	15	30	1	15	30
551+75	12-17-73	-0.6	22.9	17.6	6.0	13.1	8.4	0.0	0.0	2.0
	11-20-74	4.7	31.9	26.9	12.3	18.6	17.6	8.9	8.9	10.4
	6-5-75	5.0	33.8	31.6	14.2	21.5	24.6	13.4	11.5	17.6
	11-18-75	8.9	-	32.3	24.6	21.5	27.3	15.5	11.5	20.9
	9-22-76	17.0	-	-	-	25.7	-	23.0	15.0	31.1
	6-27-77	20.2	-	-	-	32.0	-	30.5	14.9	-
	11-2-77	24.3	-	-	-	34.4	-	33.5	20.0	-
	2-6-78	24.2	-	-	-	-	-	-	23.3	-
	6-28-78	24.8	-	-	-	-	-	-	27.6	-
	10-17-78	25.7	-	-	-	-	-	-	27.0	-
	8-27-79	25.5	-	-	-	N.F.*	-	-	32.4	-
	5-15-80	24.0	-	-	-	-	-	-	-	-

Note: All stresses in excess of 35.0 KSI are above the proportional limit of the steel and their computed values are approximate only.

*Nonfunctioning

TABLE 5: TOTAL HORIZONTAL MOVEMENT IN INCHES OF SERIES "A" MONUMENTS

Sta.	LEVEL A. Along Bottom of Wall on the Berm						
	DATE READ						
	12-17-73	11-20-74	6-5-75	9-22-76	7-1-77	10-12-78	5-5-80**
10+84	-	-	-	-	-	-	-
11+00	-	-	-	-	-	-	-
11+25	2.76	3.84	3.96	3.96	3.96	5.40	-
11+50	2.28	3.48	3.48	3.48	3.48	3.48	-
11+75	-	-	-	-	-	-	-
12+00	0.48	-	-	1.32	1.44	1.63	-
12+75	3.12	3.36	5.16	5.16	5.28	*	-
13+00	5.52	7.08	7.08	7.68	7.80	*	-
13+25	-	-	-	-	-	*	-
14+00	4.08	5.40	5.76	5.76	6.60	*	-
14+75	1.92	3.36	3.36	3.36	4.44	*	-

*Buried by temporary buttress in November-December 1977.

**All monuments buried by slope correction and buttressing in August 1979.

TABLE 6: TOTAL HORIZONTAL MOVEMENT IN INCHES OF SERIES "C" MONUMENTS

Sta.	LEVEL C: Along Top of Wall on the Fill						
	DATE READ						
	12-17-73	11-20-74	6-5-75	9-22-76	7-1-77	10-12-78	5-5-80
10+84	3.24	-	-	4.84	5.28	6.46	8.40
11+00	3.60	5.50	5.50	6.20	6.36	-	8.14
11+25	3.84	3.96	-	5.76	6.84	6.80	8.14
11+50	-	-	-	-	-	-	-
11+75	2.28	-	-	3.88	-	-	-
12+00	3.38	4.26	4.49	-	5.41	6.01	-
12+75	-	-	-	-	-	*	*
13+00	4.20	5.80	-	7.30	7.68	10.95	12.48
13+25	7.32	9.02	9.12	10.42	10.56	11.80	*
14+00	6.96	8.36	8.76	10.36	11.28	*	*
14+75	-	-	-	-	-	*	*

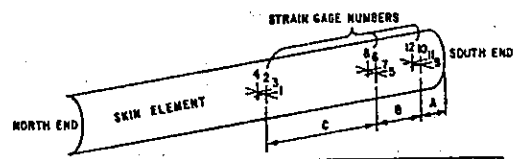
*Buried by temporary buttress in November-December 1977.

TABLE 7: STRAIN IN SKIN PLATE IN INCHES PER INCH XIO^{-6}

LEVEL	GAGE NUMBER	ORIENTATION AND LOCATION *	STATION 550+25 SKIN ELEMENT NUMBER	DATE READ 12-17-73	11-24-74	11-18-75	9-22-76	6-27-77	5-15-80	STATION 551+75 SKIN ELEMENT NUMBER	DATE READ 12-17-73	11-24-74	11-18-75	9-22-76	6-27-77	5-18-80
A	1	A-O	46	4	112	-28	-29	14	254	8	-333	-197	-214	-151	-112	-140
	3	A-I		49	133	50	99	197	492		-21	-84	-147	-116	-253	-548
	2	C-O		312	428	407	485	554	864		804	1018	1014	1061	1046	1349
	4	C-I		-330	-291	-368	-234	-77	356		-761	-674	-744	-778	-870	-1046
	5	A-O		295	302	270	257	144	440		-109	18	-53	21	28	-42
	7	A-I		295	305	323	370	309	730		-56	67	-39	42	56	-9
	6	C-O		221	404	239	302	344	402		811	968	870	957	905	1067
	8	C-I		-249	-88	-105	60	-365	183		-933	-786	-909	-907	-905	-903
	9	A-O		305	288	274	261	109	460		-144	-28	-130	-112	-105	-195
	11	A-I		270	319	526	788	835	1815		-67	49	-60	0	53	53
	10	C-O		256	407	260	337	340	290		554	663	568	626	618	827
	12	C-I		-333	-218	-288	-70	130	1231		-635	-481	-583	-546	-554	-389
B	1	A-O	57	267	204	225	190	144	297	25	-14	-98	-60	-239	-372	out
	3	A-I		200	74	411	1008	1361	2311		-21	-151	-74	-259	-168	out
	2	C-O		211	411	295	386	498	440		404	705	768	1014	1081	out
	4	C-I		-225	-7	130	130	832	2689		-435	-432	-505	48	779	out
	5	A-O		168	117	116	120	4	185		98	49	77	-62	-200	7
	7	A-I		158	116	175	333	512	1914		116	84	158	74	18	355
	6	C-O		491	649	421	466	530	386		316	663	772	1094	1168	1245
	8	C-I		-453	-344	-488	-415	-340	-38		-383	-365	-870	-902	-891	-796
	9	A-O		133	96	63	52	-32	44		204	147	186	42	-95	44
	11	A-I		109	95	204	380	618	2316		197	140	183	43	-53	786
	10	C-O		309	519	306	162	428	340		421	681	709	965	958	994
	12	C-I		-312	-275	-345	-198	24	1055		-618	-442	249	292	898	1172
C	1	A-O	69	239	249	249	209	183	-142	43	126	123	225	84	42	303
	3	A-I		218	158	235	258	239	142		98	70	183	29	35	711
	2	C-O		70	221	39	99	270	-258		-14	91	-123	-5	56	52
	4	C-I		-140	-56	-112	-38	28	-209		-49	102	32	203	418	1547
	5	A-O		126	144	95	127	126	189		154	-453	-1004	-1959	-1895	-2395
	7	A-I		56	35	-11	59	46	381		140	-456	-983	-1453	-1695	-1771
	6	C-O		168	319	140	233	309	359		-172	-625	-1463	-1731	-1997	-2794
	8	C-I		-77	168	190	311	333	319		-67	-49	-1218	-1555	-1698	-2018
	9	A-O		102	190	116	170	168	247		147	-509	-1049	-1589	-1960	-2458
	11	A-I		67	-28	14	97	74	1557		95	-547	-1060	-1545	-1790	-1511
	10	C-O		137	200	-109	82	109	235		-218	-677	-1523	-1805	-2081	-2864
	12	C-I		-175	-109	-165	138	246	1000		-46	-456	-1116	-1309	-1505	-1956

*A-O: Axial-Outside Face
A-I: Axial-Inside Face
C-O: Circumferential-Outside Face
C-I: Circumferential-Inside Face
Refer to Diagram Below

GAGE LOCATIONS



SKIN ELEMENT	LEVEL	HORIZONTAL DISTANCE BETWEEN STRAIN GAGES AND END OF SKIN ELEMENT IN FEET A	B	C	REMARKS
8	A	4.20	5.05	19.68	STATION 551+75, A, B, C
25	B	0.82	3.28	18.00	REFERENCED FROM
43	C	0.82	3.28	18.00	NORTH END OF SKIN ELEMENT
46	A	0.82	3.28	19.68	STATION 550+25, A, B, C
57	B	0.82	3.28	19.68	REFERENCED FROM
69	C	1.25	4.92	19.68	SOUTH END OF SKIN ELEMENT

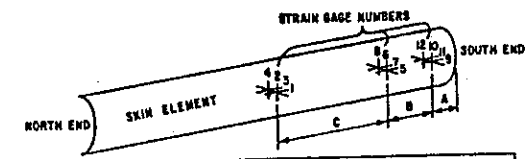
TABLE 8: STRESSES IN SKIN PLATE IN KSI

LEVEL	GAGE NUMBER	ORIENTATION AND LOCATION *	STATION 550+25 SKIN ELEMENT NUMBER	DATE READ 12-17-73	11-24-74	11-18-75	9-22-76	6-27-77	5-15-80	STATION 551+75 SKIN ELEMENT NUMBER	DATE READ 12-17-73	11-24-74	11-18-75	9-22-76	6-27-77	5-15-80
A	1	A-O	46	0.1	3.2	-0.6	-0.6	0.2	7.7	8	-9.7	-5.9	-6.2	-4.4	-3.2	-4.3
	3	A-I		1.4	3.7	1.5	2.7	5.8	15.0		-0.5	-2.5	-4.5	-3.6	-7.5	-16.7
	2	C-O		9.2	12.7	12.2	14.5	16.4	26.4		24	30.5	30.0	31.3	31.4	-
	4	C-I		-9.8	-8.6	-11.0	-1.9	-2.3	10.9		-22.7	-20.0	-22.0	-23.3	-26.0	-31.9
	5	A-O		8.9	9.0	8.0	6.5	4.2	13.4		-3.3	0.4	-1.4	0.6	0.7	-1.9
	7	A-I		8.9	9.0	9.5	11.0	9.0	22.3		-1.6	2.0	-0.8	1.2	1.6	-0.3
	6	C-O		6.6	11.9	7.2	9.0	10.2	12.3		-24.3	29.0	26.0	28.0	27.3	32.5
	8	C-I		-7.4	-2.5	-3.3	1.7	-10.9	5.6		-28.0	-23.4	-27.1	-27.2	-27.0	-27.5
	9	A-O		9.2	8.4	8.0	7.7	8.3	14.0		-4.2	-0.6	-3.8	-3.3	-3.2	-5.9
	11	A-I		8.0	9.5	15.6	23.4	25.0	-		-1.9	1.5	-1.8	0	1.6	1.6
	10	C-O		7.7	12.2	7.8	10.1	10.2	8.0		16.6	19.9	17.0	18.8	18.5	25.2
	12	C-I		-10.0	-6.5	-8.6	-2.1	3.9	-		-19.1	-14.4	-17.5	-16.4	-16.6	-11.9
B	1	A-O	57	8.0	6.1	6.8	5.7	4.3	9.1	25	-0.4	-2.9	-1.8	-7.2	-11.2	out
	3	A-I		6.0	2.2	12.3	30.2	39.4	-		-0.6	-4.5	-2.2	-7.8	-5.0	out
	2	C-O		6.3	12.3	8.9	11.6	14.9	13.4		12.1	21.2	23.0	30.4	32.4	out
	4	C-I		-6.8	-0.2	3.9	3.9	25.0	-		-13.1	-13.0	-15.2	1.4	23.4	out
	5	A-O		5.0	3.6	3.5	3.6	0.1	5.6		2.9	1.5	2.3	-1.9	-6	0.2
	7	A-I		4.7	3.5	5.3	10.0	15.4	-		3.5	2.5	4.7	2.2	0.5	10.8
	6	C-O		14.7	19.5	12.6	14.0	15.9	11.8		9.5	19.9	23.2	32.8	35.0	-
	8	C-I		-13.6	-10.3	-14.6	-12.5	-10.2	-1.2		-11.5	-11.0	-26.1	-27.1	-26.7	-24.3
	9	A-O		4.0	2.9	1.6	1.8	1.0	1.3		6.1	4.4	5.6	1.3	-2.9	1.3
	11	A-I		3.3	2.9	6.1	11.4	18.6	-		5.9	4.2	5.5	1.3	-1.6	24.0
	10	C-O		9.3	15.6	9.2	4.9	12.8	10.4		12.6	20.4	21.2	29.0	28.7	30.3
	12	C-I		-9.4	-8.3	-10.4	-5.9	0.7	32.2		-18.5	-13.3	7.5	8.8	26.9	-
C	1	A-O	69	7.2	7.5	2.5	6.3	5.5	-4.3	43	3.8	3.7	6.8	2.5	1.3	9.2
	3	A-I		6.5	4.7	7.1	7.7	7.2	4.3		2.9	2.1	6.5	0.9	1.1	21.7
	2	C-O		2.0	6.6	1.2	3.0	8.1	-7.9		-0.4	2.7	-3.7	-0.2	1.7	1.6
	4	C-I		-4.2	-1.7	-3.4	-1.1	0.8	-6.4		-1.5	3.1	1.0	6.9	12.5	-
	5	A-O		3.8	4.3	2.9	3.8	3.8	5.8		4.6	-13.6	-30.1	-45.0	-44.7	-73.0
	7	A-I		1.7	1.1	-0.3	1.8	1.4	11.6		4.2	-13.7	-29.5	-42.2	-44.0	-54.0
	6	C-O		5.0	9.6	4.2	7.0	9.3	10.9		-5.2	-18.8	-41.3	-44.2	-45.0	-85.2
	8	C-I		-2.3	5.0	5.7	9.3	10.0	9.7		-2.0	-1.5	-36.3	-42.5	-44.0	-61.5
	9	A-O		3.1	5.7	3.5	2.1	5.0	7.5		4.4	-15.3	-31.5	-43.0	-45.0	-75.0
	11	A-I		2.0	0.8	0.4	2.9	2.2	-		2.9	-16.4	-31.8	-42.5	-44.5	-46.1
	10	C-O		4.1	6.0	-3.3	2.5	3.3	7.2		-6.5	-20.3	-44.0	-44.5	-45.1	-87.4
	12	C-I		-6.3	-3.3	-5.0	4.1	7.4	30.5		-1.4	-13.7	-33.5	-38.3	-42.0	-59.7

*A-O: Axial-Outside Face
A-I: Axial-Inside Face
C-O: Circumferential-Outside Face
C-I: Circumferential-Inside Face
Refer to Diagram Below

Note: Tensile stresses above 35 KSI are in excess of proportional limit and are not shown.

GAGE LOCATIONS



SKIN ELEMENT	LEVEL	HORIZONTAL DISTANCE BETWEEN STRAIN GAGES AND END OF SKIN ELEMENT IN FEET A	B	C	REMARKS
8	A	4.20	5.05	19.68	STATION 551+75, A, B, C
25	B	0.82	3.28	18.00	REFERENCED FROM
43	C	0.82	3.28	18.00	NORTH END OF SKIN ELEMENT
46	A	0.82	3.28	19.68	STATION 550+25, A, B, C
57	B	0.82	3.28	19.68	REFERENCED FROM
69	C	1.23	4.92	19.68	SOUTH END OF SKIN ELEMENT

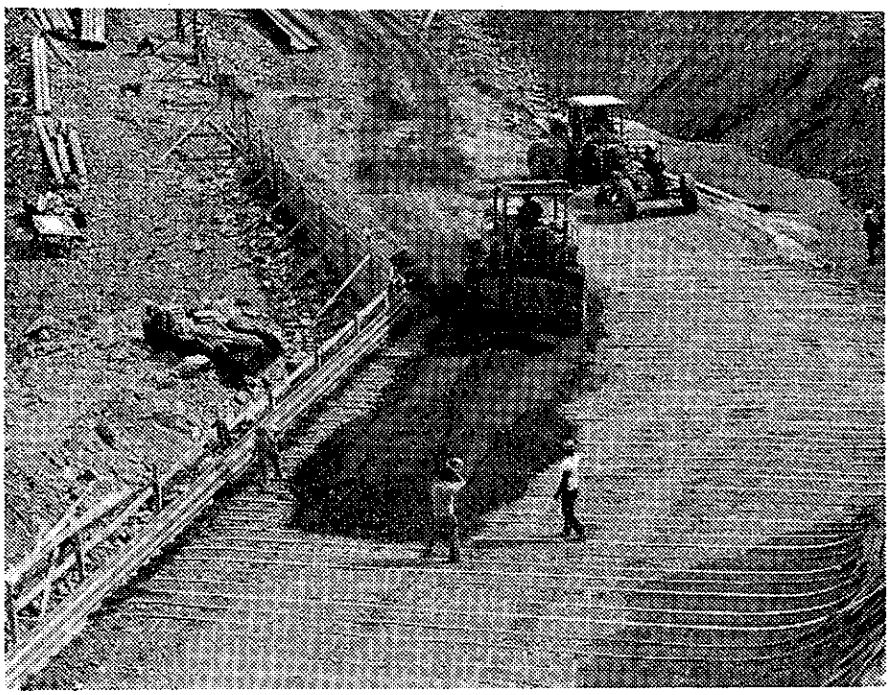


Photo 1 - Reinforced Earth Construction in 1972
(07-LA-39)

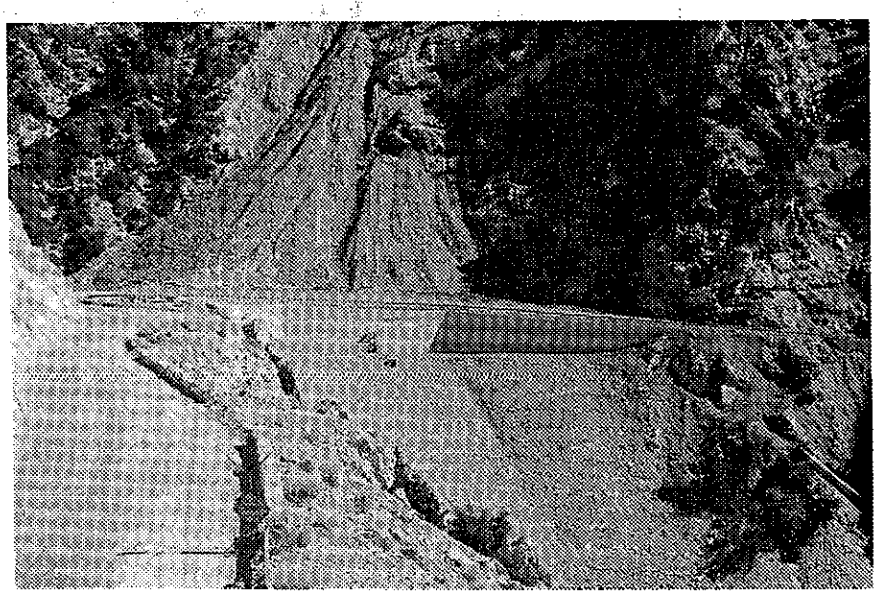


Photo 2 - Completed Facility in 1972
(07-LA-39)

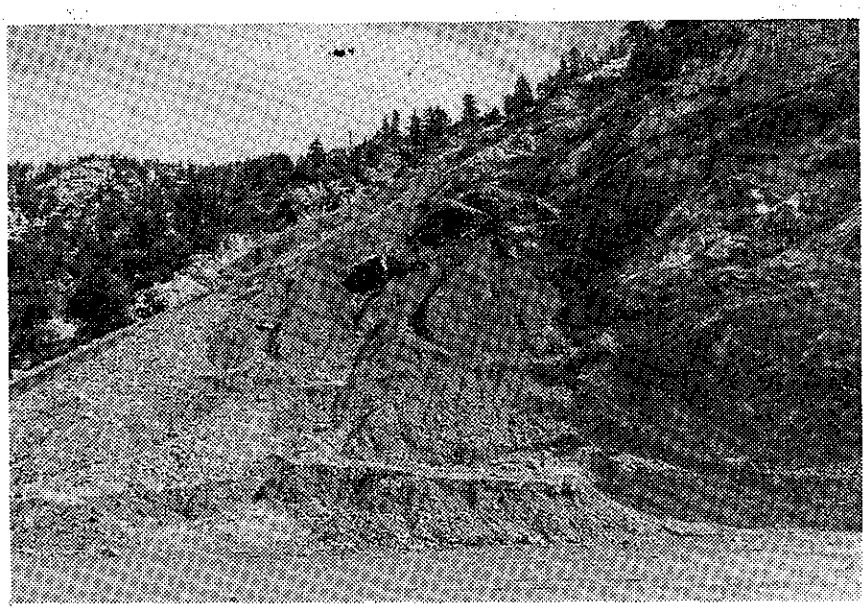


Photo 3 - Continuous Accumulation of Slide Debris Behind Wall

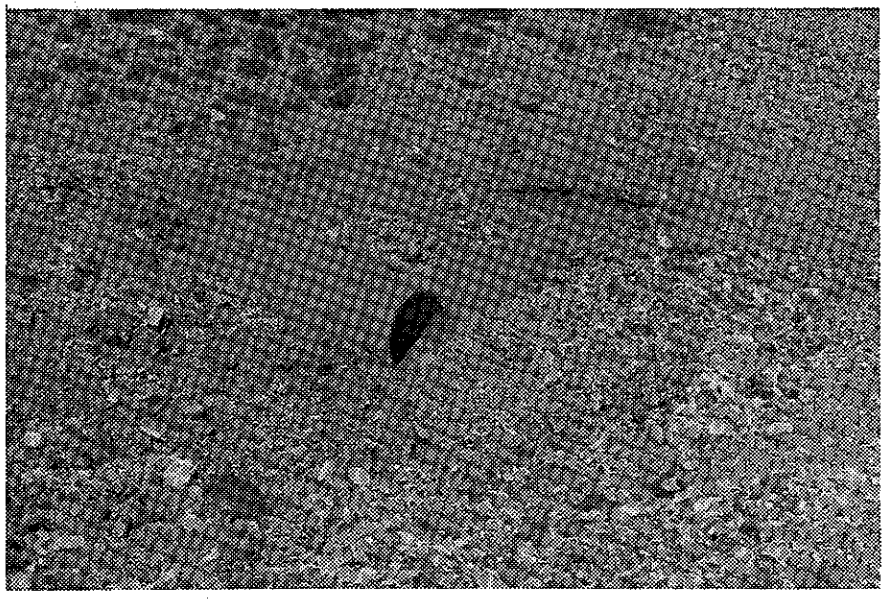


Photo 4 - Culvert Inlet Behind Wall (Note pervious nature of channel entrance.) - June 1978

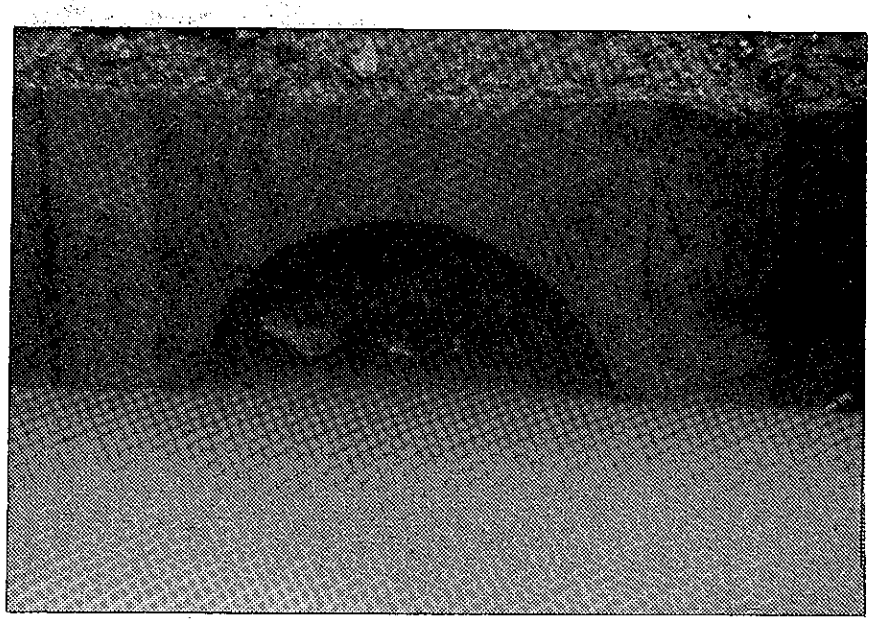


Photo 5 - Plugged Culvert Inlet During Winter Storm

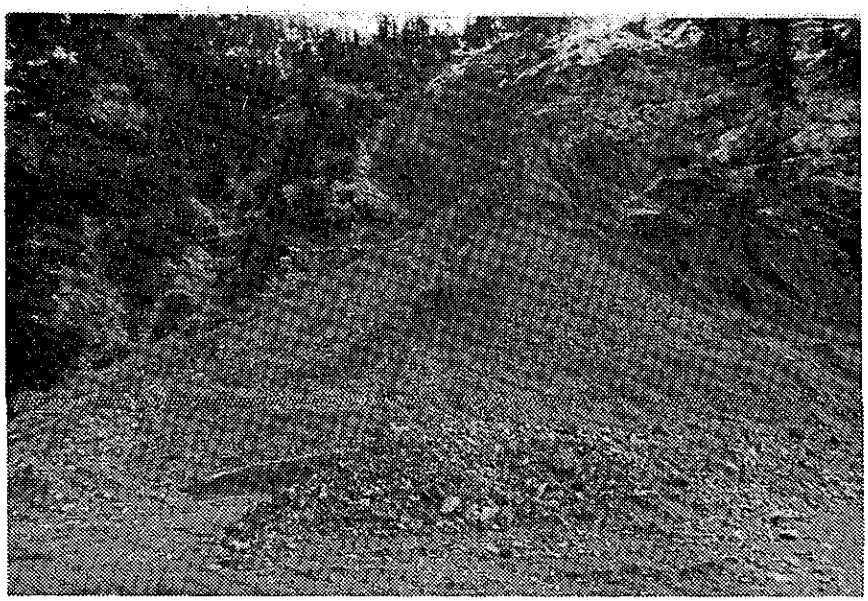


Photo 6 - Slide Debris Prior to Removal Behind Wall

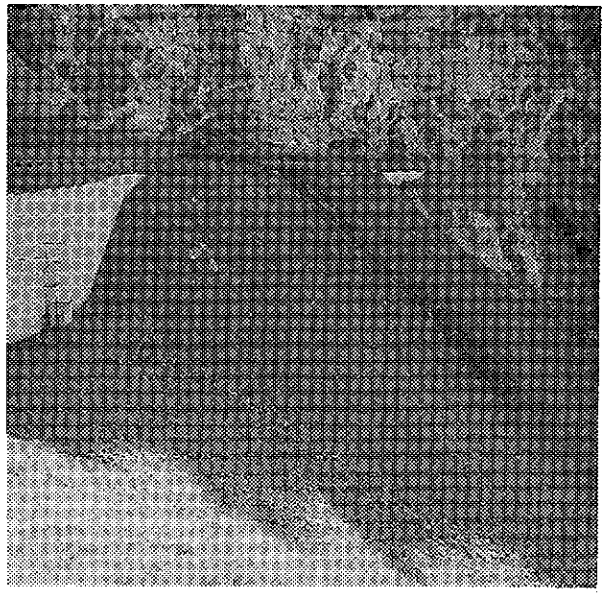


Photo 7 - Slide Material Being Pushed Over Wall Face to Form Temporary Buttress (November-December 1977)

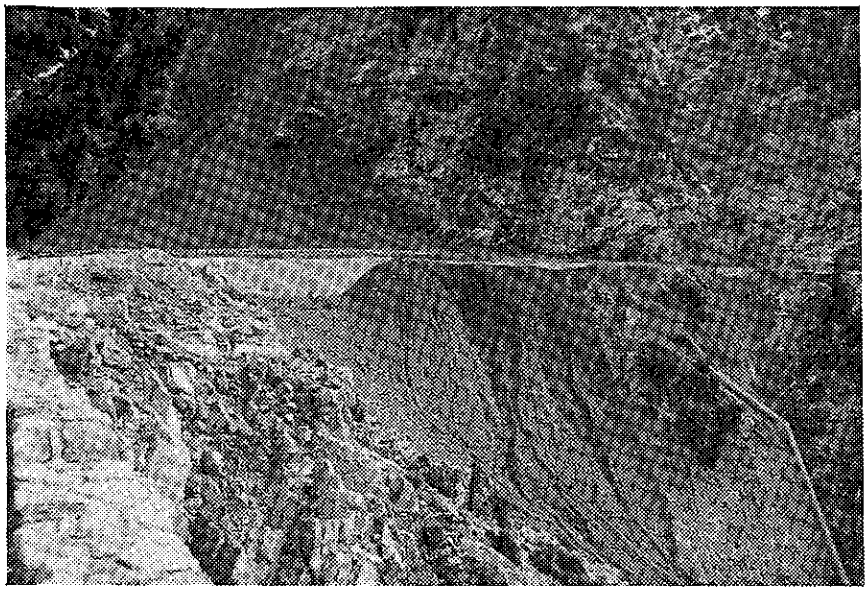


Photo 8 - Erosion on Temporary Buttress (Winter of 1977)

Photo 9 - Erosion at Toe of Slope Below Wall (June 1978)

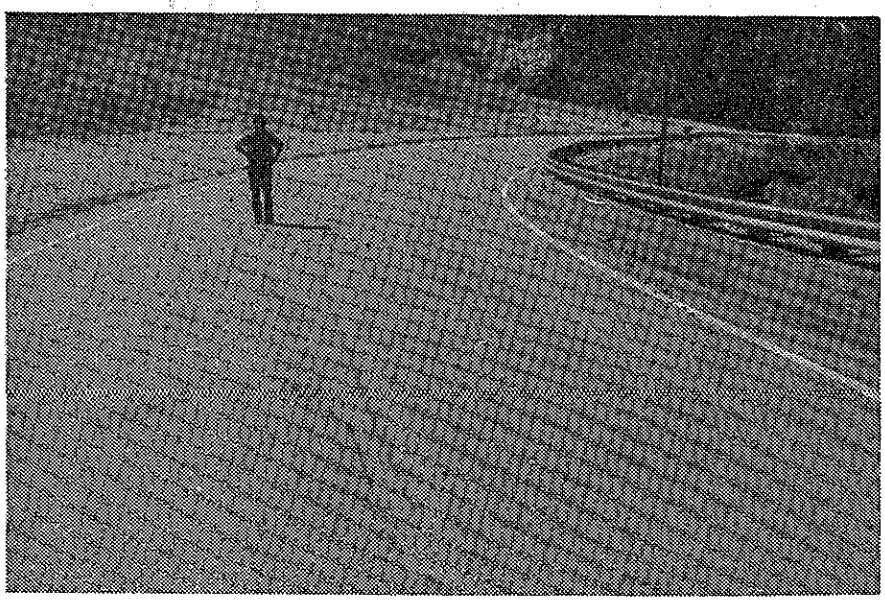


Photo 10 - Cracks in Pavement at North Flank of Wall Near Centerline (June 1978)

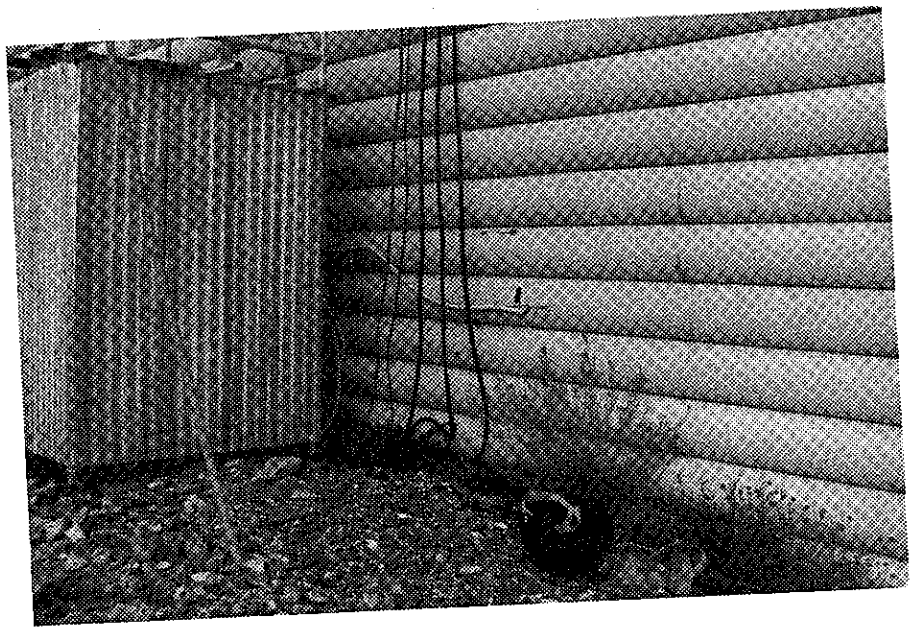


Photo 11 - Strain Gage Location at Level B, Station 551+75 Prior to Removal

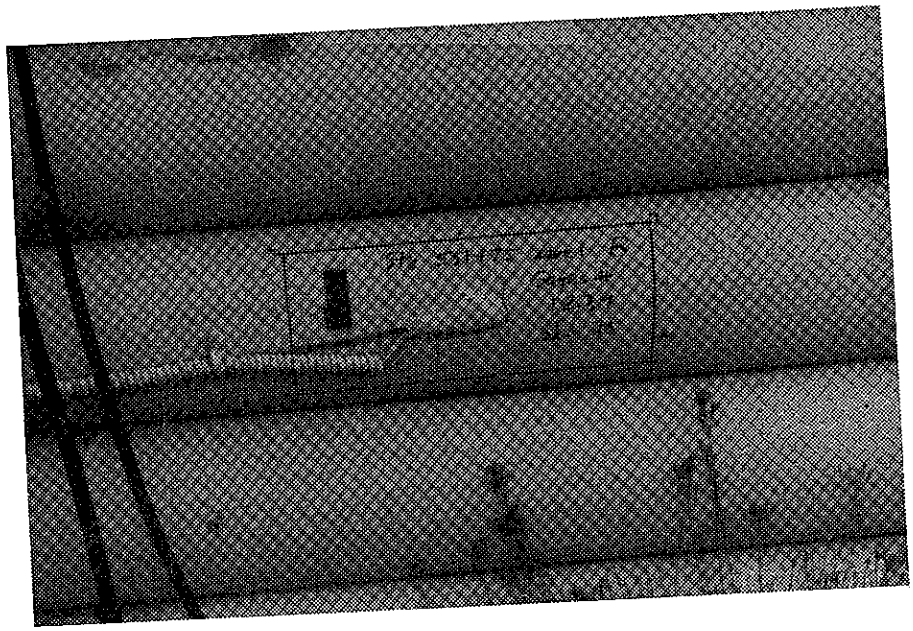


Photo 12 - Strain Gage Location at Level B, Station 551+75 Prior to Removal

Photo 13 - Cutting Operation to Remove Strain Gage (October 1978)

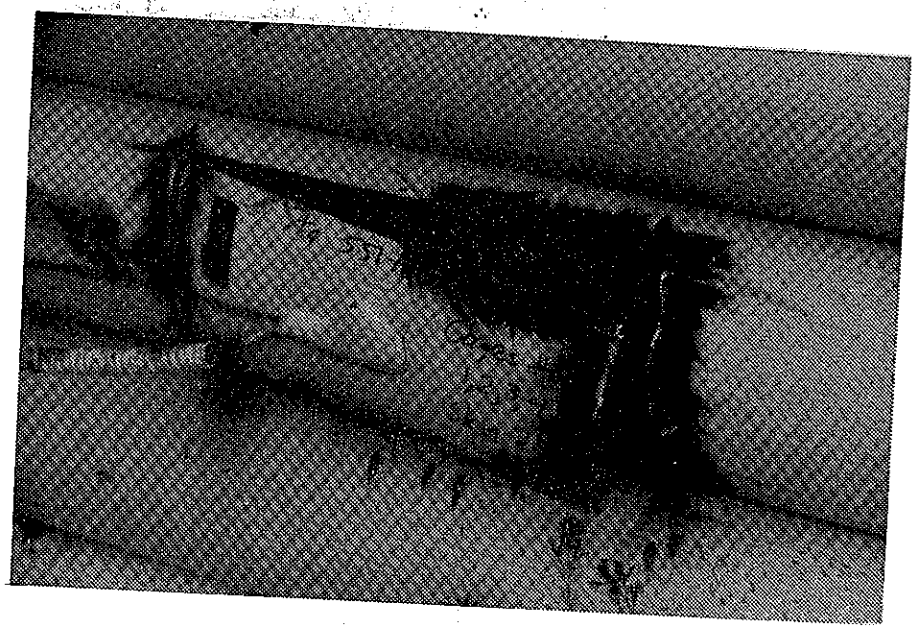


Photo 14 - Strain Gage Removal

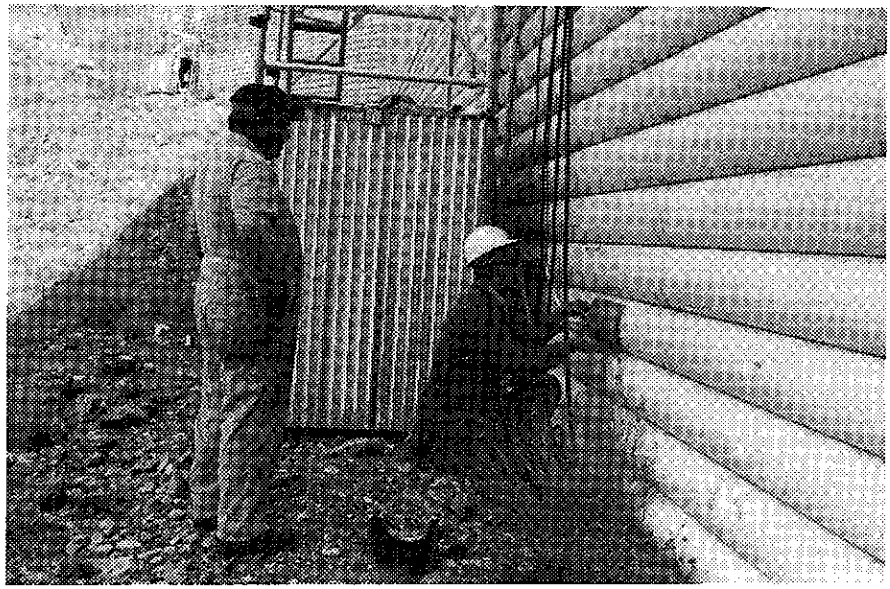


Photo 15 - Replacement of Skin Plate
Following Strain Gage Removal

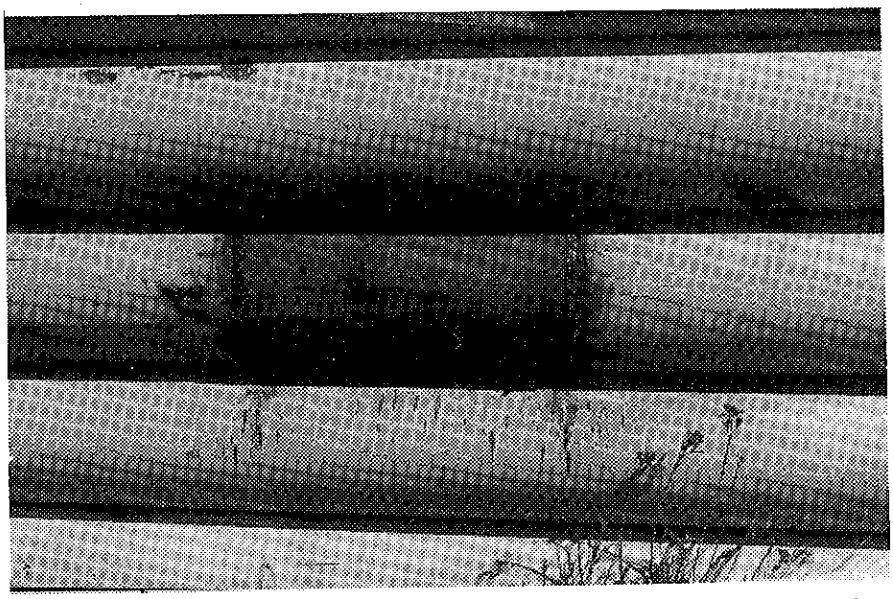


Photo 16 - Replacement of Skin Plate
Following Strain Gage Removal

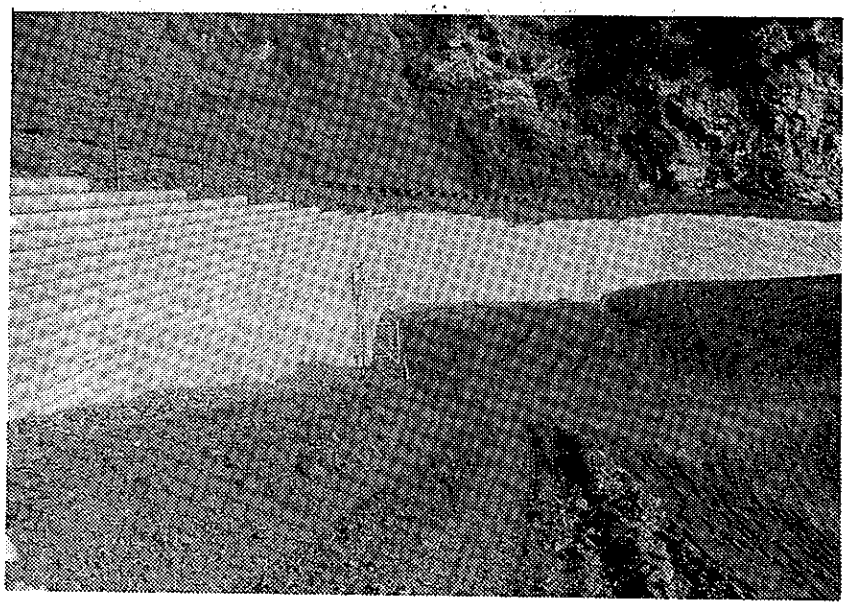


Photo 17 - Resloping and Construction of 10 ft of Additional Toe Buttress (July-August 1979, note stain on wall face of south flank from temporary buttress.)

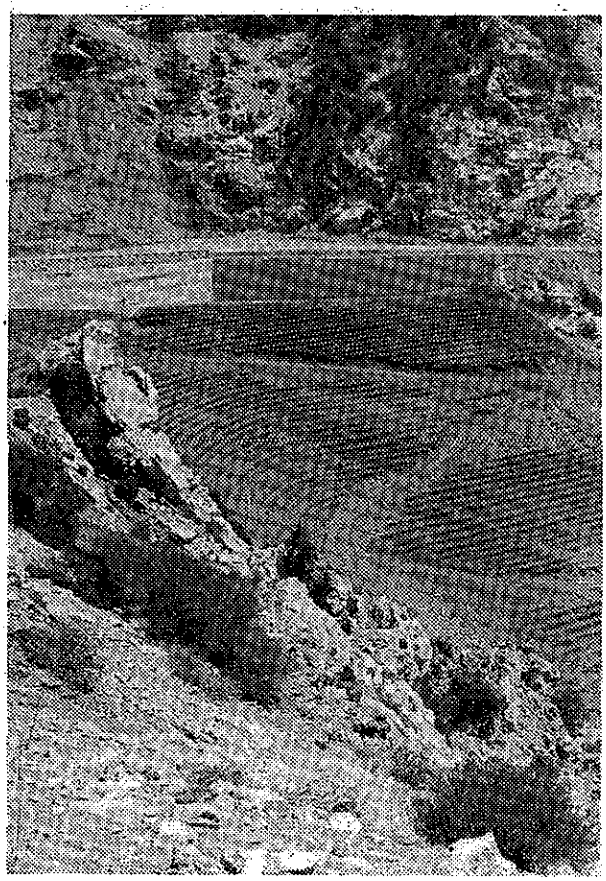


Photo 18 - Distant View of Slope Terracing and Access Road (August 1979)

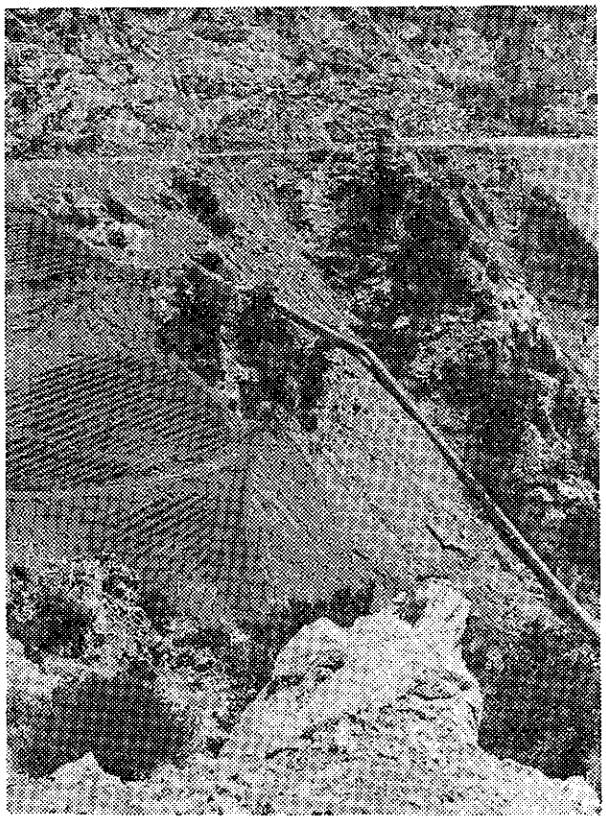


Photo 19 - View of Lower Portion of Slope and Restored 84-Inch Culvert (August 1979)

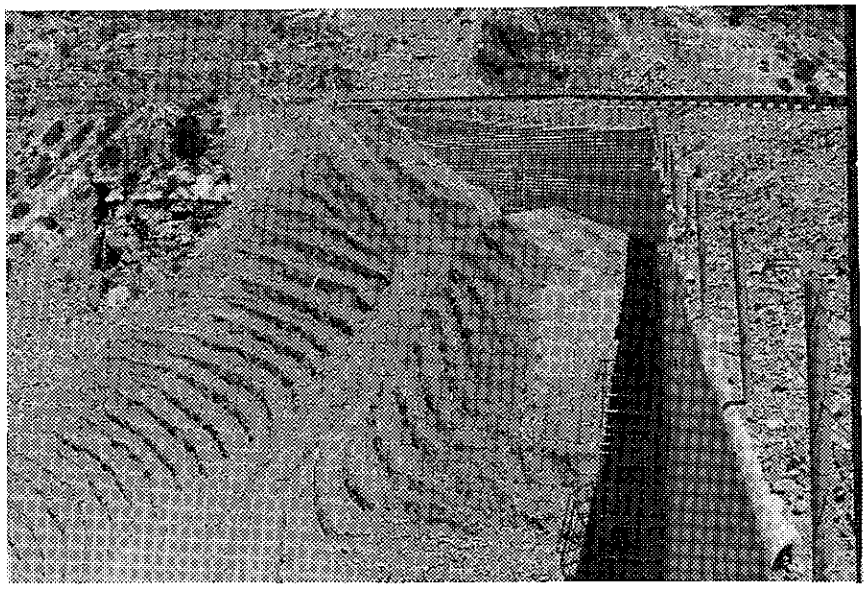


Photo 20 - Side View of Wall Looking North at Access Road on Slope (August 1979)

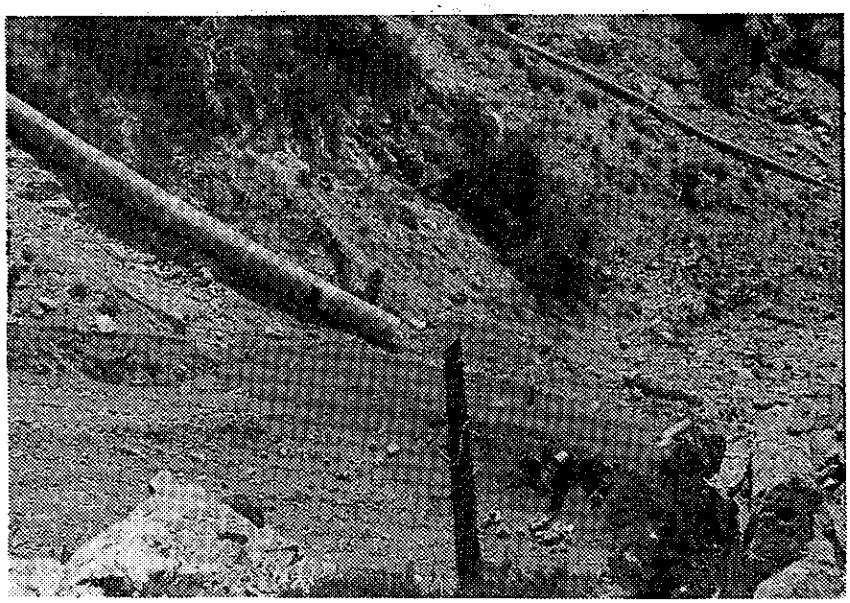


Photo 21 - Catchment Berm at Toe of Slope to Retain Eroded Material (August 1979)

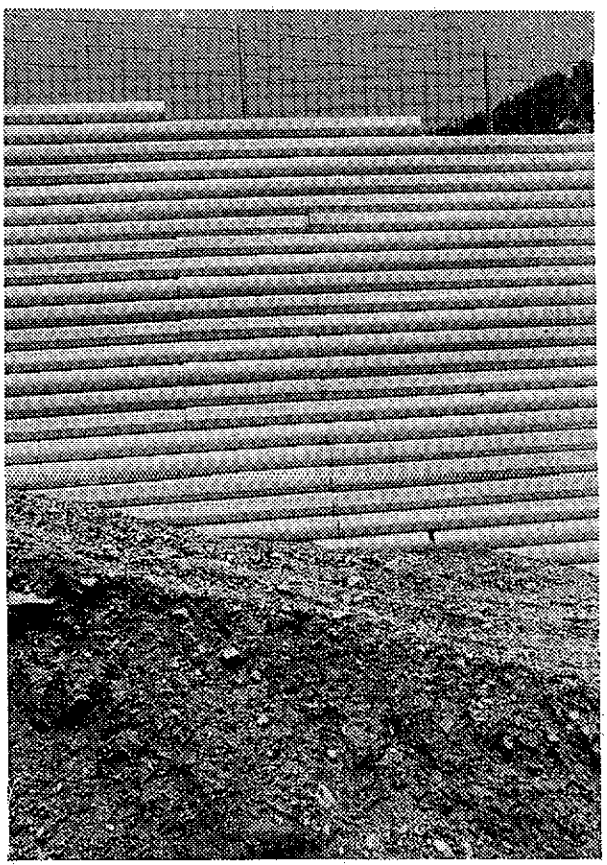


Photo 22 - Extension and Separation of Skin Plate Joints on North Flank (May 1980)

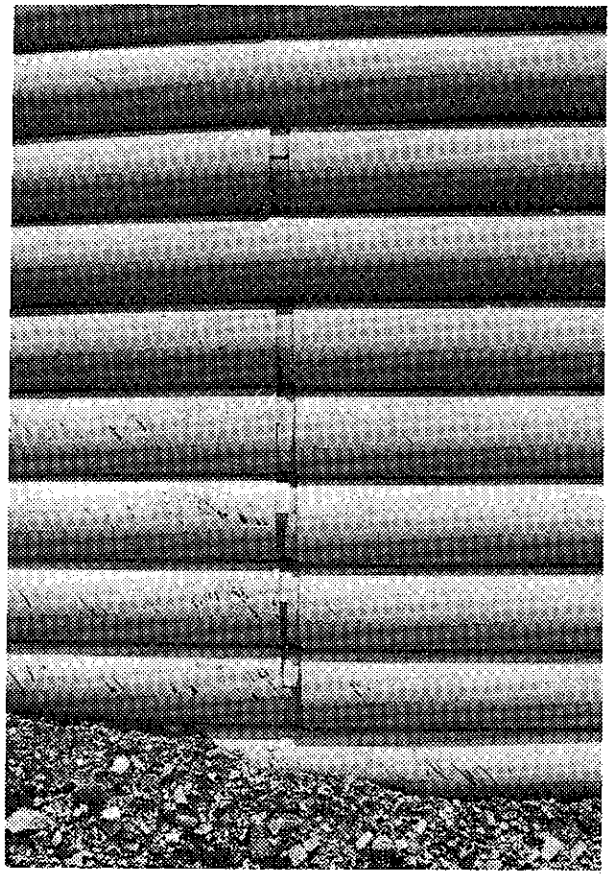


Photo 23 - Close-up of Skin Plate Joint Separation on North Flank (May 1980)

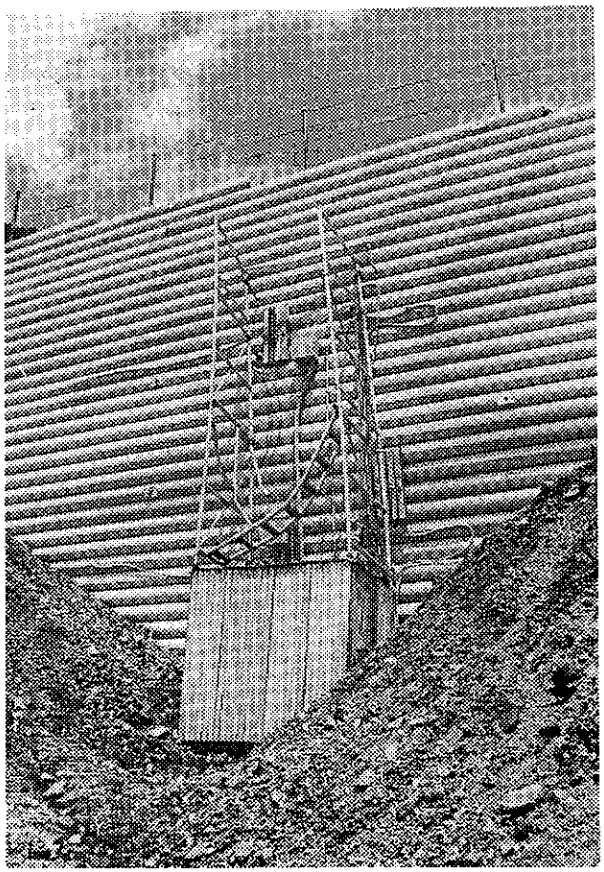


Photo 24 - Skin Plate Joint Separation Near Instrumentation Station 550+25, North Flank (May 1980)

Photo 25 - Close-up of Skin Plate Joint Compression in Center Chord (May 1980)

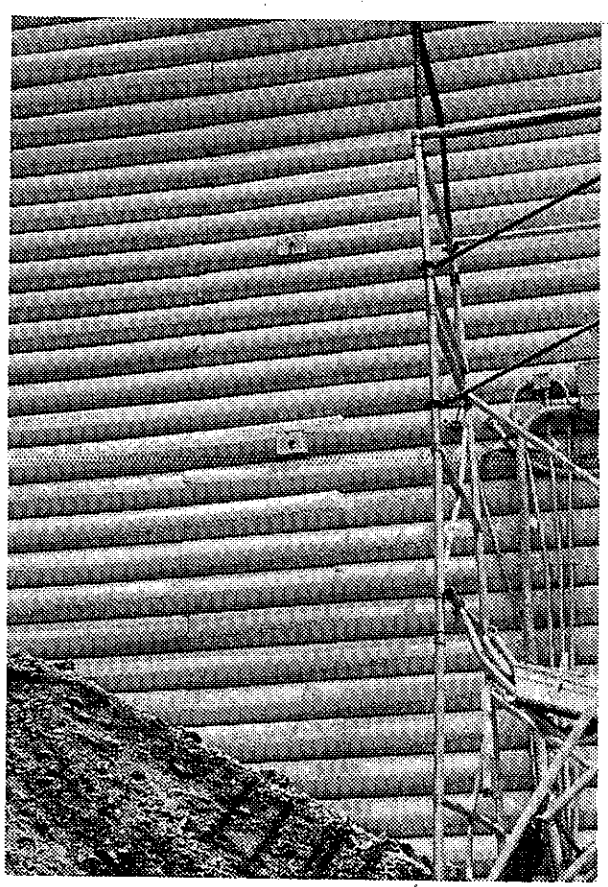


Photo 26 - Evidence of Skin Plate End Gouging and Distortion Near Instrumentation Station 551+75, Center Chord (May 1980)

Photo 27 - Water Flowing into Drainage Channel Behind Wall and Disappearing Rapidly into Pervious Channel (June 1980)

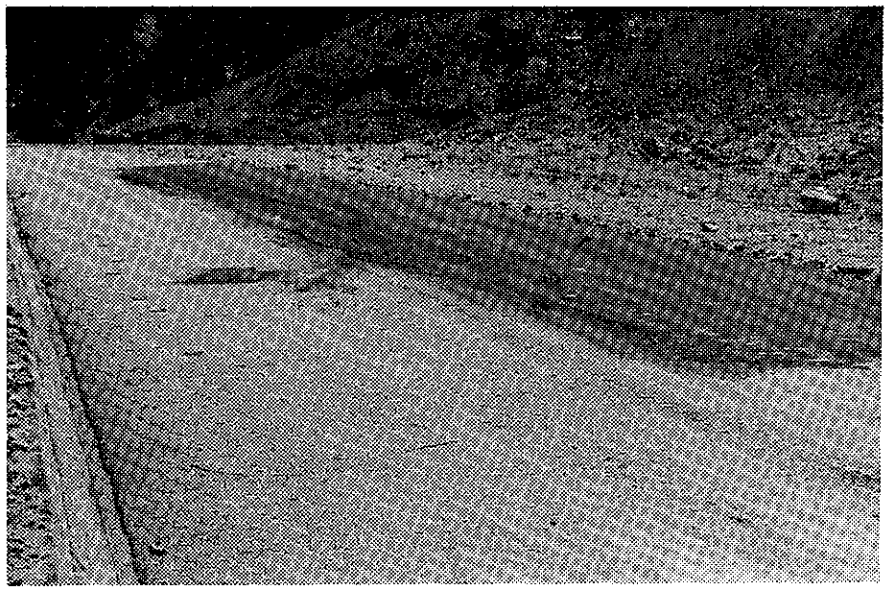


Photo 28 - Patched Pavement Behind South Flank of Wall (June 1980)

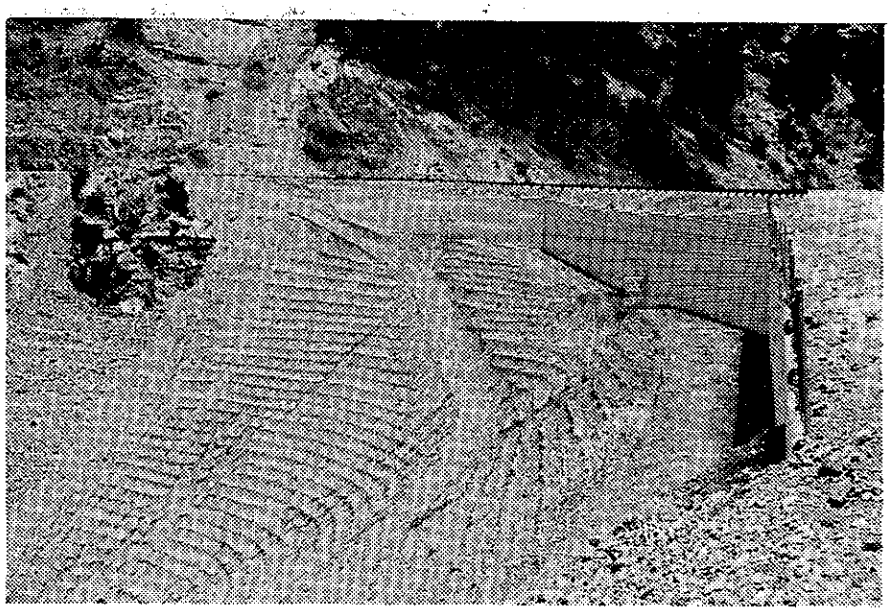


Photo 29 - Side View of Wall Looking North at Access Road on Slope, After One Rainy Season (May 1980)

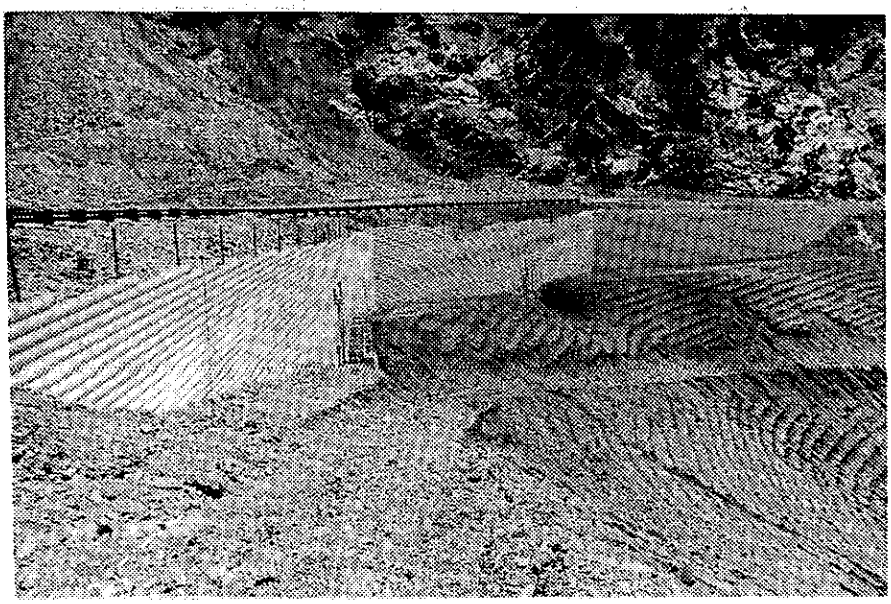


Photo 30 - Side View of Wall Looking South at Access Road on Slope, After One Rainy Season (May 1980)

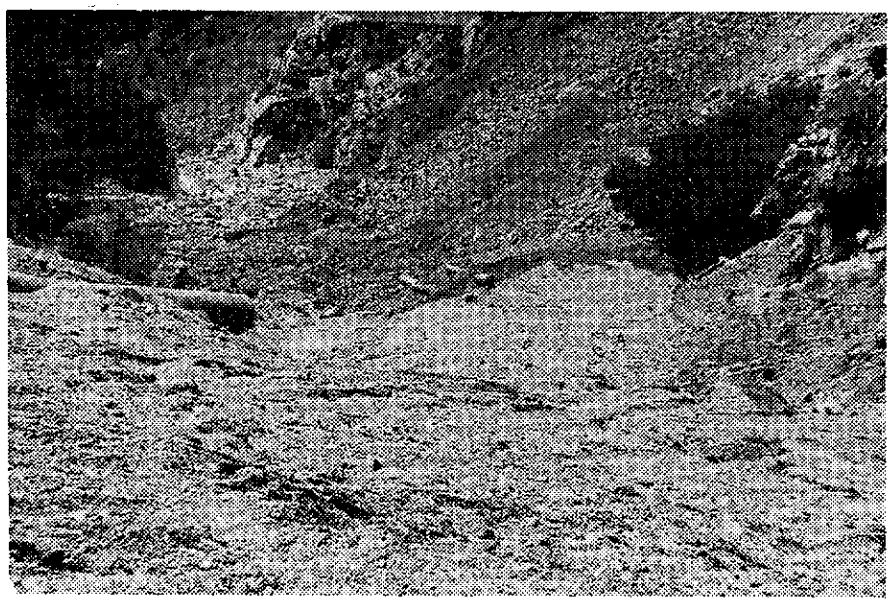


Photo 31 - Catchment Basin at Toe of Slope with Retained Eroded Material, After One Rainy Season (May 1980)